FINAL REPORT

Regenerating Longleaf Pine on Hydric Soils: Short- and Long-term Effects on Native Ground-Layer Vegetation

SERDP Project SI-1303

June 16, 2009

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Strategic Environmental Research and Development Program

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Regenerating Longleaf Pine on Hydric Soils: Short- and Long-term Effects on Native Ground-Layer Vegetation

Final Report

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LIST OF ACRONYMS

ANOVA	Analysis of variance
BA	Basal area
CB	Experimental treatment with chopping and bedding
CEC	Cation exchange capacity
CF	Experimental treatment with chopping and flat-planting
CHB	Experimental treatment with chopping, herbicide, and bedding
CI	Confidence interval
CM	Experimental treatment with chopping and mounding
COMP	Competition Omission Monitoring Project
CVS	Carolina Vegetation Survey
DBH	Diameter at breast height
DHT	Dominant height
DIF1	Response variable = change in 1-hour timelag fuels after burning
DIF10	Response variable = change in 10-hour timelag fuels after burning
DIF100	Response variable = change in 100-hour timelag fuels after burning
DIF1000	Response variable = change in 1000-hour timelag fuels after burning
DoD	Department of Defense
EU	Experimental number
F	Experimental treatment with flat-planting only
FS	Forest Service
GSRA	Greater Sandy Run Area
HB	Experimental treatment with herbicide and bedding
HDIF	Response variable = change in herbaceous biomass after burning
HF	Experimental treatment with herbicide and flat-planting
HM	Experimental treatment with herbicide and mounding
HPCT	Herbaceous vegetation cover
HWT	Herbaceous vegetation biomass
ISA	Indicator species analysis
LITDIF	Response variable = change in litter after burning
LLP	Longleaf pine
m	meter
MCB	Marine Corps Base
MCBCL	Marine Corps Base Camp Lejeune
MINITAB	Statistical software package
mm	millimeter
MRPP	Multi-response permutation procedure
NCSU	North Carolina State University
NCVS	North Carolina Vegetation Survey
NMS	Non-metric multidimensional scaling
NRCS	Natural Resources Conservation Service
OM	Organic matter
PAR	Photosynthetically active radiation
PCTBURN	Response variable = percent of sample unit area burned

pH	Measure of soil acidity
QMD	Quadratic mean diameter
RCD	Root collar diameter
RCW	Red-cockaded Woodpecker
RELDIF	Response variable = change in total litter as a proportion of preburn
RH	Relative humidity
RTP	Research Triangle Park
S	Species richness (species per unit area)
SAS	Statistical Analysis Software
SDIF	Response variable = change in woody biomass after burning
SE	Standard error
SERDP	Strategic Environmental Research and Development Program
SON	Statement of need
SPCT	Shrubby vegetation cover
SWT	Shrubby vegetation biomass
T&E	Threatened and Endangered, species protection status
TERS	Threatened, endangered and at-risk species
TOTDIF	Change inf total fuels with burning
TPH	Trees per hectare
UNC	University of North Carolina
USA	United States of America
USDA FS	United States Department of Agriculture Forest Service
USDI FWS	United States Department of Interior Fish and Wildlife Service
USFWS	United States Fish and Wildlife Service
USMC	United States Marine Corps

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EXECUTIVE SUMMARY

Across the southeastern United States longleaf pine woodlands support a wide range of military training activities and provide suitable habitat for diverse communities of plants and animals, including remarkable numbers of threatened, endangered, and at-risk plant and animal species (TERS). As a result of historical land uses, large areas previously dominated by longleaf pine now support different forest types, especially on wetter more productive sites, and active forest management is required to restore them. Restoring longleaf pine on poorly drained sites where there is no remaining natural seed source, and doing so without further losses of any remaining native herbaceous vegetation, is arguably one of the most difficult challenges to restoration ecologists. This project addressed that problem.

Methods to establish longleaf pines on well-drained sites are well-understood, but not so on poorly drained sites that occupy much of the outer coastal plain, including Marine Corps Base Camp Lejeune, North Carolina. On wetter sites foresters typically rely on intensive management actions to prepare the sites for planting trees. Effective site preparation methods minimize seedling mortality and promote early, rapid growth, but also potentially reduce the herbaceous component of the ground layer plant community. Vigorous herbaceous ground layer that covers at least 40% of the area is a defining standard for high quality red-cockaded woodpecker foraging habitat (US FWS 2003). In addition to direct effects of plantation establishment, longer term effects on habitat quality accrue through time as the new forest develops. These effects also are not well-documented for poorly drained sites, nor are the driving ecological processes known.

This study posed two primary research questions to address short- and long-term effects of plantation management on hydric soils, and identified five specific objectives.
Question 1: What are the effects of selected site preparation methods on ground layer vegetation and on longleaf pine establishment and early growth? *Objective 1* -- Quantify plant species abundance and diversity at 1, 2, and 3 years after planting; *1a* -- Describe treatment effects on prescribed fire behavior; *2*-- Quantify seedling survival; *3*-- Quantify longleaf pine seedling growth and emergence from the grass stage at 3 years after planting. **Question 2: What are the persistent effects of past plantation establishment on the structure and composition of the ground layer vegetation on sites that historically supported longleaf pine?** *Objective 4* -- Compare vegetation in undisturbed longleaf pine stands with vegetation in plantations on comparable sites; *5* --Develop conceptual models that describe how past plantation establishment practices affect current vegetation. A replicated field experiment was installed to address the first question, and data were collected from established plantations and compared to mostly undisturbed longleaf pine reference sites. All work was conducted on Marine Corps Base Camp Lejeune, located on the outer coastal plain of North Carolina.

Site preparation experiment (Question 1)-- In 2003 we installed a randomized block designed experiment with eight low- to moderate-intensity site preparation treatments

used or likely to be used at Camp Lejeune replicated on 5 blocks, for a total of 40 experimental units. Eight site preparation treatments were applied in the summer of 2003, consisting of a check (no treatment applied), six combinations of two initial vegetation control treatments (chopping or herbicide) with three planting site conditions (flat [no additional treatment], mounding, or bedding), and a more intense treatment of chopping, herbicide, and bedding. The treatments are referenced as follows: flat or check (F), chopping and flat (CF), herbicide and flat (HF), chopping and mounding (CM), herbicide and mounding (HM), chopping and bedding (CB), herbicide and bedding (HB), and chopping, herbicide, and bedding (CHB). In 2004, 2005 and 2006 we monitored pine seedlings for survival and growth and we measured ground layer vegetation and species richness. Results of pine seedling growth were combined with existing longleaf pine growth models to investigate possible site preparation effects on the production of stand structure (longleaf pine size and stem density) suitable for red-cockaded woodpecker foraging habitat. *Plantation and reference site comparison (Question 2)*-- In 2003 and 2004 we sampled plantations sites at least 18 years old using standardized methods and acquired archived data for reference natural areas sampled in the same way. Species composition, environmental characteristics, and measure of species diversity were compared for these two groups.

Longleaf seedling survival, about 70% after two years, did not vary among site preparation treatments. In contrast, both competition control method and planting site conditions showed treatment differences. Compared to chopping, herbicide treatments resulted in greater seedling root collar diameter and height. Similarly, raising the planting surface by bedding or mounding enhanced seedling growth relative to growth in flat-planted sites. Analysis of environmental conditions adjacent to individual seedlings indicated that the benefits were likely related to better control of competing vegetation associated with herbicide treatments, bedding and mounding. Also, results indicated that excess moisture on poorly drained sites is an important limiting factor for root collar growth. Site preparation treatments that improve drainage, as well as reduce competition for light and other resources, can be expected to maximize longleaf pine seedling growth.

With respect to changes in ground layer vegetation, two main patterns emerged: (1) the effects of chemical application persisted through the study but effects of bedding or mounding diminished, and (2) the patterns of treatment effects on total vegetation abundance and to a lesser degree species richness tracked treatment effects on the woody component or the shrub functional group. Both of these observations are be related to the facts that shrubs were the most abundant vegetation group on the sites and that the herbicide treatment formulated to control the shrubs was very effective. Overall, results were consistent with previous studies on flatwoods sites, including the finding that three years after site preparation there was no significant treatment effect on species richness and, except for two treatments (HB and HM), vegetation cover was not different from the flat planted plots. Measurement of prescribed fire behavior in the study plots two years after planting indicated that site preparation treatments can affect how much of the site burns, how hot the fires burn, and how much fuel remains after burning, all factors related to the effectiveness of prescribed fire for maintaining ground layer diversity.

Bedding and mounding tended to reduce temperatures and percent of the area burned, while chopped sites had more uniformly distributed higher maximum temperatures.

Key messages to land managers include (1) Bedding or mounding as applied in this study should have no short-term adverse effect on ground layer vegetation cover, richness or composition. (2) The herbicide formulation used in this study (imazapyr and triclopyr) and broadcast prior to planting longleaf pine seedlings effectively reduced woody plant cover, and had no lasting effects on other plant groups. (3) There was a tendency for all herbaceous groups to benefit from the herbicide effect of reducing the shrubby dominance. Shrubs were not eliminated by this treatment, but herbaceous cover tended to increase by the third year after site preparation. (4) Prescribed burning appears to be critical for maintaining any benefits to the herbaceous community, and prescriptions for management burns may have to be modified to ensure effective burning in site-prepared locations. (5) Although the plant community richness or abundance was not changed much by site preparation in the first 3 years after treatment, the beds and troughs produced by bedding are expected to persist throughout the age of the plantation and to change the microhabitats within the flatwoods by creating both drier and wetter than average conditions that are likely to favor different vegetation.

Models of plantation development based on seedling growth data and previously published longleaf pine growth models indicated that there can be substantial differences (>20 years) in the time needed to achieve the size and density of trees required for red-cockaded woodpecker foraging. On landscapes where foraging habitat is extremely limited, site preparation choices that promote early growth may be necessary, but managers must balance the negative effects of plantation management on the ground layer foraging habitat standard (40% herbaceous cover) that was not achieved in maturing plantations.

Plantations on average showed lower species richness measured at small spatial scales, but at the scale of 0.1 ha species richness was not affected by plantation management. In plantations, no species were totally lost or added, but the relative abundance of some characteristic species (*Aristida stricta* and *Gaylussacia dumosa*) was significantly reduced in plantations. On average, plantation sites had about 20% herbaceous cover in the ground layer vegetation, about half of the standard established for red-cockaded woodpecker foraging habitat. Reference vegetation averaged 43% herbaceous cover overall. The lack of difference in species richness except at the smallest scales indicates that reasonably diverse communities are maintained in plantations, and suggests the potential for restoring a diverse groundcover without adding species. However, a few dominant species apparently are sensitive to habitat modifications created during establishment and growth of plantations. Although thinning the canopy and prescribed burning may invigorate the groundcover, we predict that the effectiveness of prescribed burning may be limited by the lack of fine fuels resulting from the significantly reduced herbaceous cover in plantations.

Implications for TERS habitat restoration-- Site preparation potentially may affect TERS habitat management in the short-term by direct impacts on ground layer and prescribed

fire behavior, and over a longer time by accelerating the rate of plantation development with its associated loss of herbaceous cover in general and of fine fuel producing grasses specifically (Figure 1). Site preparation choices must balance the need to grow trees quickly with the possible adverse effects on fire behavior in particular. Neither the rates of change in ground layer vegetation nor the mechanisms driving those observed changes is well-understood for poorly drained sites, potentially some of the most biologically diverse sites in North America. Current research efforts directed at understanding longleaf pine community dynamics and response to management disturbance are focused on upland sites. Continued study of these dynamics in the poorly drained habitat would provide a basis for developing much needed restoration approaches and protocols.

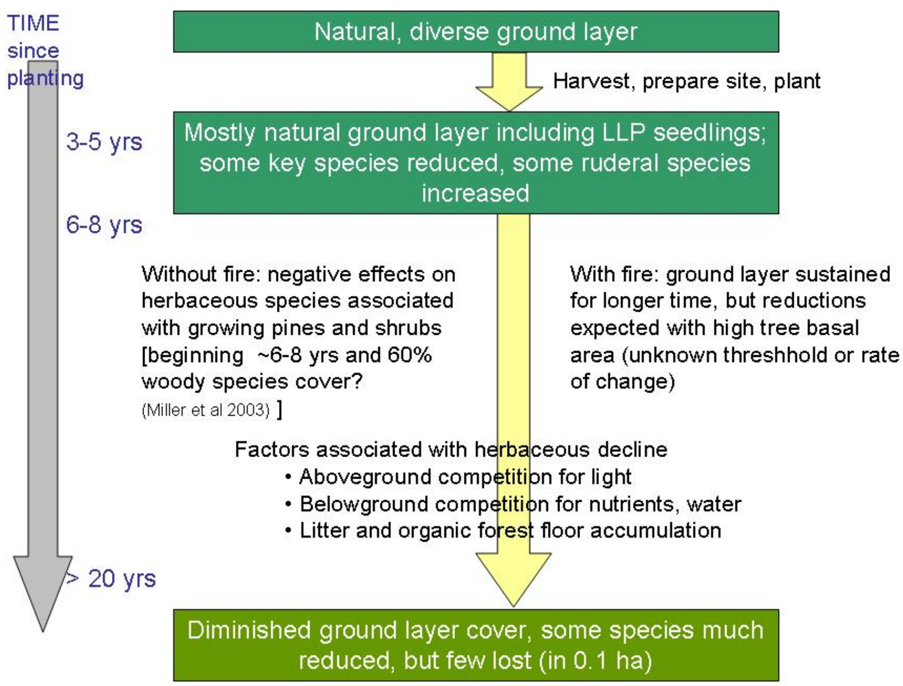


Figure 1. Changes in the ground layer vegetation following longleaf pine plantation establishment on a site with a characteristic native ground cover at the time of site preparation. There are few short-term direct effects of low- to moderate-intensity methods (as used in this project) on the herbaceous ground cover. Plantation development is associated with much reduced cover, but few species are lost. Site preparation choice may affect the rate of decline by accelerating the rate tree growth or changing the behavior of prescribed fire.

1. Introduction

1.1. Project Context and SERDP Relevance

The work supported the second objective of SON number CSSON-02-05 (The Impact of Military Training Activities, Land Management Actions and Species/Habitat Sensitivities on Terrestrial Threatened and Endangered Species). Objective 2 identified the need to quantify disturbances related to land management actions that affect the occurrence and vitality of threatened or endangered species.

The project was planned to quantify the effects of management actions to re-establish longleaf pine (LLP) to sites it historically occupied. Establishing longleaf pine is essential for restoring the longleaf pine ecosystem upon which the endangered red-cockaded woodpecker (RCW) depends. In addition to RCW the LLP ecosystem supports the following Threatened and Endangered (T&E) species listed as priority species in the SON: Eastern Indigo Snake, Wood Stork, Gopher Tortoise, Rough-leaved Loosestrife, and Michaux's Sumac.

As a result of historical land uses, especially fire suppression and silvicultural preferences for other species, large areas once dominated or co-dominated by LLP now support different forests, especially on wetter or more productive sites. Altered forest types include loblolly pine or slash pine forests, hardwood forests, and mixed pine-hardwood types. Ground layer vegetation in today's forests has also changed. The original fire-maintained longleaf system supported diverse herbaceous communities, and presumably a diverse arthropod community, but the increased basal area and lack of burning in today's forests have lead to increases in woody species and reductions in herbaceous diversity. Land managers are attempting to restore the longleaf ecosystem, and at least one contemporary SERDP project (CS-1114) focused on the longleaf pine restoration effort. CS-1114 included the use of fire and thinning to restore the structure of LLP pine communities on well-drained upland sites; however, it did not address the difficult problem of LLP restoration to sites where LLP is gone, nor did it attend to restoration challenges on wetter sites. Restoring LLP on productive mesic to wet sites where there is no remaining natural seed source, and doing so without further losses of any remaining native herbs, is arguably one of the most difficult challenges to restoration ecologists. This project addressed that problem.

Although natural regeneration methods are often preferred for important conservation areas, artificial regeneration must be used in sites where the LLP seed source has been lost. Challenges for regeneration, especially for LLP, on wetter sites include controlling competition for other vegetation and providing improved drainage for seedling establishment. Solutions to these problems have included intensive practices, such as shearing, bedding, and piling, that can effectively establish pines. But there is evidence that these same practices change the ground layer vegetation such that native herbaceous species are lost or reduced and native shrubs increase. Several studies indicate that the quality of the ground layer vegetation is critical to the health of the LLP ecosystem, particularly with regard to RCW fecundity (James et al. 1997, Hardesty et al. 1997). It is

hypothesized that the ground layer vegetation quality influences the arthropod prey needed to fledge young. Based largely on these studies, the draft recovery plan for the RCW (US Fish and Wildlife Service 2003) set guidelines for the condition of the understory in RCW habitat to include 40% cover of native grasses and herbs, and recommends less intensive regeneration methods. Although less intensive site preparation methods may provide for some LLP establishment, managers are concerned that low intensity approaches may jeopardize pine establishment and put at risk the long-term objectives for LLP forests on the landscape. Managers need better information in order to assess risks associated with various site preparation actions.

The results of this work were expected to provide a scientific foundation for assessing management choices for managing longleaf pine and associated species on the landscape. Specifically, the results were to be used to support site preparation decisions, potentially retaining management tools that might otherwise be restricted in the revised RCW Recovery Plan (US Fish and Wildlife Service 2003). Although longleaf pine dominated landscapes vary considerably with geography, almost all include wetter sites. Thus, results of the proposed work should be applicable to all military installations with responsibilities for recovering the Red-cockaded Woodpecker. Implementing results from this study will ensure the sustainability and native biodiversity of DoD managed ecological systems and reduce litigation potential for DoD installations with RCWs.

1.2. Research Questions, Technical Objectives, General Approaches

The overall goal of this project was to strengthen the scientific basis for selecting site preparation methods to restore longleaf pine on somewhat poorly drained sites, while retaining and restoring the diverse ground layers of these sites. The project objectives are related to two general research questions.

Question 1: What are the effects of selected site preparation methods on ground layer vegetation and on longleaf pine establishment and early growth?
Objective 1 --Quantify plant species abundance and plant community diversity in treatment areas prior to site preparation and planting, and at 1, 2, and 3 years after planting. *Objective 1a* -- Describe effects of site preparation treatments on prescribed fire behavior. *Objective 2*--Quantify seedling survivorship at 1 and 2 years after planting. *Objective 3*-- Quantify LLP seedling growth and emergence from the grass stage at 3 years after planting.

Question 2: What are the persistent effects of past plantation establishment on the structure and composition of the ground layer vegetation on sites that historically supported longleaf pine or a pine mixture including longleaf pine? *Objective 4*--Compare vegetation in undisturbed longleaf pine stands with vegetation in plantations, at least 18 years old, on comparable sites. *Objective 5*—Develop conceptual models that describe how past plantation establishment and other silvicultural practices affect current vegetation.

The first question was addressed with a controlled field experiment to quantify short-term effects of selected site preparation methods on Leon soils, the most common hydric soil on Camp Lejeune. Nearly 30% of the soils are hydric soils, and Leon fine sand is the most common hydric soil occurring on 9.5% of the base. This question was addressed by comparing current conditions in maturing plantations with known management histories to undisturbed "reference" stands in the mid-Atlantic coastal plain of North Carolina. Data for plantations were collected as part of this project using methodology of the Carolina Vegetation Survey (CVS). Data for reference sites were acquired from the CVS database.

1.3 Organization of this report

A general technical background is provided to frame the research questions (Section 2). The field experiment that was installed to address Question 1 is then described in Section 3.1, and is followed in Sections 3.2 – 3.5 by detailed methods, results and accomplishments associated with specific research objectives 1-3. Section 4 details methods and accomplishments related to Objective 4. Results from both short- and long-term effects tudies are combined in a discussion of implications for red-cockaded woodpecker habitat restoration and TERS plant species in Sections 5.1 and 5.2. Section 6 briefly describes monitoring needs for experimental plots and conclusions are found in Section 7.

Table 1.1. SI-1303 Final Report organization. Sections are related to specific technical objectives as indicated.

Section	Technical Objective	Brief description
1		Introduction: Relevance to SERDP SON, problem statement, research goal and technical objectives, organization of report
2		General technical background setting context of entire project
3	1, 1a, 2, 3	Introductory comments for study of short-term effects of site preparation
3.1	1, 1a, 2, 3	Design of field experiment
3.2	2, 3	Pine seedling survivorship and early growth related to site preparation: methods, results, discussion
3.3	3	Relating early growth of planted longleaf pine seedlings to changes in microenvironments produced by site preparation: methods, results, discussion
3.4	1	Effects of site preparation treatments on ground layer vegetation structure and species richness: methods, results, discussion
3.5	1a	Effects of site preparation treatments on prescribed fire behavior: methods, results, discussion
4.1	4	Comparison of vegetation in managed pine plantations with remnant natural pine woodlands: methods, results, discussion
4.2	5 (in part)	Use of longleaf pine growth models to quantify treatment effects on rate of red-cockaded woodpecker foraging habitat growth
5.1	5 (in part)	Short-term and long-term effects of plantation management and implications for RCW habitat production
5.2	5 (in part	Discussion of plantation management effects on TERS plants
6		Monitoring recommendations
7		Conclusions: objectives met, unresolved issues

2. General Technical Background

2.1. The longleaf pine ecosystem: habitat loss, Threatened and Endangered (T&E) species, management challenges

At the time of European settlement, longleaf pines dominated or co-dominated forests on about 37 million hectares (92 million acres) (Frost 1993). During the centuries following settlement, large areas were lost to agriculture, pasture, and development. The condition of the remaining longleaf forests, about 3.3 million acres in 1994 (Outcalt and Sheffield 1996), has been altered by plantation establishment and fire suppression. Historical land uses have also fragmented the longleaf landscape. Few intact parcels remain, and the current distribution of the endangered red-cockaded woodpecker (RCW) is correlated with remaining large tracts. The largest RCW populations are found on Federal lands (US FWS 2003). Longleaf pine habitat loss, fragmentation, and degradation have been cited as contributing factors for the listing of at least 10 animals and 26 plants as federally endangered or threatened. Federal land mangers have responsibilities for promoting the recovery of these listed species.

The ground layer vegetation is a unique and functionally important component of longleaf pine plant communities (Walker 1998). On frequently burned sites, mixtures of grasses, forbs, and low shrubs dominate this layer. Although the composition of ground layer vegetation varies regionally, throughout the range, site moisture and soil type strongly affect local composition. In general, mesic to wet sites are more diverse than dry sites. The mesic savanna communities of the Atlantic and Gulf coastal plains are remarkable for their botanically interesting plant species, such as orchids and carnivorous plants, and for their extraordinarily high levels of species richness (Walker and Peet 1983, Peet and Allard 1993, Walker 1993, Peet 2006). In terms of ecosystem function, the ground layer provides fine fuels to carry the surface fires that sustain the entire ecosystem, and evidence indicates it supports a diverse arthropod community (Folkerts et al. 1993, Hermann et al. 1998, Hanula and Engstrom 2000).

Recent research reports link the condition of ground layer vegetation to RCW fecundity and population health. Red-cockaded woodpecker groups defending territories with predominantly grassy or herbaceous ground layers had higher fecundity than nearby groups in shrub-dominated territories (James et al. 1997, Hardesty et al. 1997). This finding has resulted in a dilemma for land managers. How can the acreage of longleaf pine stands be maintained or even increased without disrupting the quality of natural ground layer vegetation? Moreover, in the absence of native ground layers, how can pine forests be regenerated in a way that facilitates restoring the ground layer to the degree possible?

2.2. Artificial regeneration of longleaf pines

Where there are no existing longleaf trees to provide seeds, establishing longleaf pines requires artificial regeneration methods. Although more costly than natural regeneration, artificial regeneration offers the potential benefits of high survival rates, controlled

spacing, and faster emergence from the grass stage. Poor survival reported in artificially regenerated longleaf pine stands is typically associated with improperly grown stock or unsatisfactory field conditions during planting and through the first year (Dennington and Farrar 1983; Boyer 1988). Site preparation prior to planting can improve the conditions for seedling establishment and early growth.

2.3. Site preparation for artificial regeneration

The primary goals for site preparation are (1) to reduce or eliminate vegetation that can compete with the crop species for resources, particularly nutrients and water and (2) improve the planting site with regards to availability of resources for planted seedlings (e.g., by improving drainage on wet sites or concentrating organic matter and nutrients near seedling roots). By design, practices that control competing vegetation reduce the abundance and vigor of other species, at least in the short term. Practices that make resources more available to planted seedlings can also change the spatial distribution of resources available for remaining understory plants.

Site preparation practices fall into several categories including prescribed fire, mechanical, manual, and herbicide treatments (USDA FS 1989, Lowery and Gjerstad 1991). Within categories specific treatments can range from low to high intensity. Although it is common to combine several methods for preparing a single site, we briefly describe the single treatments here. (USDA FS 1989 reviews site preparation operations and their effects on planted pines and other vegetation.) In the next section, we briefly summarize effects of site preparation methods on moderately to somewhat poorly drained soils. Additional details are included in subsequent sections that present results in the context of previous research studies. Public land managers charged with managing to achieve multiple objectives, for example, maintaining biodiversity or retaining cover for military training, typically do not choose the most intensive practices. For that reason, we discuss practices likely to be of interest to this group.

Prescribed fire is the planned use of fire and its effects are largely a function of vegetation type and fire severity. Factors that affect the immediate fire effects and are considered when planning prescribed fires include fuels (abundance, composition, distribution, moisture content), topography, weather, time of year, and predicted fire behavior (flame length and rate of spread). Although the abundance of many species of the longleaf pine ecosystem is reduced immediately following prescribed fire, these species usually persist in the stand. Vegetation can recover from fire by sprouting from root systems or rhizomes, or by germination from seed. Overall, fire is not detrimental to fire-adapted species, such as those found in the longleaf pine ecosystem. In fact, in many instances fire stimulates flowering, fruiting, and population vigor. (For reviews of fire effects on vegetation see Brown and Smith 2000, Robbins and Myers 1992.)

Eight mechanical methods are widely used for site preparation on coastal plain pine sites, and can be categorized based on potential for soil disturbance by erosion, compaction, and nutrient loss (USDA FS 1989). Potential for disturbance is low for chopping and shearing, scarifying, and ripping tools; moderate for piling and bedding tools; and high

for raking and disking tools. Scarifying, ripping, piling or windrowing, raking and disking are not relevant to this study and are not discussed further. Disturbance to on-site vegetation is directly related to the potential for soil disturbance, as will be described below. All are used to reduce vegetation by removing aboveground and/or belowground vegetation. There is little doubt that intensive practices result in both successful pine establishment, and marked loss of ground cover structure and composition.

Chopping, shearing, and bedding are low to moderate impact mechanical treatments typically used in plantation establishment on multiple use public lands. A *rolling drum chopper* pulled by a tractor cuts and chops herbaceous and woody vegetation up to 5 inches in diameter. It breaks vegetation above the surface and chops into the soil severing rhizomes and roots. Cuts made by blades on the drum may increase water infiltration and incorporate organic matter into the soil. Species able to sprout from roots or rhizomes generally recover after chopping, but double chopping or using heavy choppers can severely reduce native grasses. Chopping is moderately effective for controlling competition with planted pines (Grelen 1959, Outcalt 1983, Pienaar and Rheney 1992). *Shearing* tools (K-G blades or V-blades) are mounted on tractors and cut vegetation at the ground line. Shearing is used to clear an area for planting. As the blade pushes the cut vegetation across the soil surface, the topsoil can be moved and organic matter redistributed. Re-sprouting vegetation can still compete with planted seedlings. *Bedding* tools consist of one or more sets of disks that pile topsoil and litter into continuous raised surfaces for planting. An hourglass shaped roller typically follows the disks to help smooth and settle the bed. Beds vary in height from 8-15 inches, which can direct or impede surface water movement. Bedding concentrates organic matter in the beds and on flat sites provides better drainage for the planting sites. The practice has been shown to improve early pine growth (Derr and Mann 1970, Pritchett 1979, Haines and Pritchett 1964, Outcalt 1984, McKee and Wilhite 1986), but effects on other ground layer species are not carefully reported.

A variety of herbicides are used in the management of forest vegetation (USDA FS 1989, Shiver et al. 1991, Lowery and Gjerstad 1991, Litt et al. 2001), and the mode of action varies with the chemical. Herbicides vary in effectiveness according to the plant species and treatments can be made more specific by using directed application methods. In site preparation, herbicides may be used alone or in combination with prescribed burning. The choice of herbicides is usually dependent on the known effect on the most abundant competitor species, e.g. shrubs or grasses or hardwoods. However, effects on non-target species are not as well documented (Nelson 1998, Litt et al. 2001).

2.4. Site preparation for pine plantations on to somewhat poorly drained sites

Longleaf pine has been traditionally planted on the driest sites, despite its historical distribution across moisture gradients from the most xeric to somewhat poorly drained soils. Industrial forests favored loblolly pine or slash pine on wetter sites because they were more easily established and considered more productive on such sites, although subsequent analyses are changing that perception (Shoulders 1990). Consequently, there are few studies of site preparation for the artificial regeneration of longleaf pine. These

have been conducted on well-drained sites, mostly on the Gulf coastal plain, and confirm that controlling competition is critical for LLP plantation establishment (Sheer and Woods 1959, Boyer 1988).

Numerous studies have compared the effects of site preparation methods used to artificially regenerate other pines on poorly drained coastal plain sites (Reviewed in USDA FS 1989). Experimental treatments within individual studies often include both single method treatments (for example, a single prescribed fire) and combinations of operations (for example, chopping followed by bedding). Comparing studies is complicated because experimental treatments, species, and site conditions vary among studies. In spite of the difficulties of comparing studies, some general patterns emerge with regard to the relative effectiveness of site prep methods for pine regeneration and on plant community structure and composition.

First, with respect to seedling survival and growth, prescribed fire is inferior to treatments using mechanical methods (Haines and Pritchett 1964, Schultz 1976, Conde et al. 1983a, b; Swindel et al. 1986, 1988). Depending on resource management objectives and planting densities, however, fire may produce acceptable densities and growth rates. Additionally, fire may have desirable effects on native ground cover species (Robbins and Myers 1992).

Second, increasing the intensity of a mechanical treatment reduces the survival and recovery rate of woody competitors, and increases herbaceous cover shortly after treatment (up to 3 years) (Haines and Prichett 1964, Schultz 1974, Swindel et al 1986, McKee and Wilhite 1986, Zutter et al. 1987, Zutter and Miller 1998, Miller et al. 1999, Kush et al. 1999). Further, intense treatments, such as shearing, piling, raking, and high bedding, result in a short-term shift in species composition to include a greater abundance of ruderal species (for examples, Schultz and Wilhite 1974, Swindel et al. 1986). In the absence of prescribed burning, woody vegetation typically re-captures the sites after 10 years. Although this general pattern is established, there are no studies that completely identify herb species or address changes in community structure at multiple scales. Differential impacts on sensitive species may remain undetected.

Finally, initial increases in pine productivity associated with intense site preparation may not persist through the rotation of the plantation. That is, the pine production on less intensively treated sites catches up with production on intensely treated sites (Outcalt 1984, Buford and McKee 1987, Zutter and Miller 1998). Thus, managers must balance the cost of site preparation method with the uncertainty of long-term productivity.

Extending the results of studies with other pine species to longleaf pine must be considered carefully. It is widely held that LLP seedlings are very sensitive to competing vegetation and to flooding (Boyer 1988). And it is broadly assumed that such sensitivities render them more difficult to establish than slash or loblolly pines. While there are data that indicate LLP sensitivity to competition, there are no definitive studies that demonstrate an increased sensitivity to flooding. Wahlenburg (1946) notes this

possibility but provides no data. It is not certain that using site preparation practices to improve drainage for seedlings is necessary.

In summary, existing site preparation studies are not adequate for current management needs. They focus on different species, were conducted in distant geographic regions, and often fail to capture adequately treatments effects on diverse ground layer vegetation.

2.5. Long-term effects of plantation establishment on ground cover composition and structure

Long-term effects of plantation establishment on ground layer vegetation are not reported in the literature. Walker and van Eerden (1996) and Smith et al. (2001) report reduced species richness at small scales in plantations (30-40 years old) compared to remnant sites in the fall line sandhills. At scales of 0.1 ha species richness in xeric site plantations nearly equaled remnant sites, however several key ground cover species were significantly reduced. The cover of the dominant bunch grass, *Aristida stricta*, and the dominant dwarf shrub, *Gaylussacia dumosa* were reduced in xeric longleaf pine plantations in Chesterfield County, SC (Walker, unpublished data). Smith et al. (2001) report a similar pattern across a moisture gradient at the Savannah River Site, SC. Additionally, they found that the deviation from remnant condition increased with soil moisture status. That is, the relative difference between mesic plantations and comparable undisturbed vegetation was greater than that difference on xeric sites. These observations suggest that the effects of plantation establishment are likely to be greater as site productivity increases; however, there is no information available to examine this hypothesis on mesic to wet-mesic sites. Understanding this relationship is important if we are to develop site-specific restoration protocols.

The ability to forecast the effects of management practices on longleaf pine ecosystems is limited by our understanding of the ecosystem processes. The general responses of longleaf pine and of the ground layer vegetation are described, but underlying mechanisms are not understood. Recent research has been directed toward understanding the dynamics of unmanaged longleaf pine populations (Brockway and Outcalt 1998, McGuire et al. 2001), in part, to ascertain if longleaf pine naturally regenerates in patches or gaps, as opposed to requiring large openings for regeneration. This finding has implications for choosing even-aged or uneven-aged management strategies. Understanding belowground process is an active area of research. Though research continues, ecologists are far from fully specifying a process model for longleaf pine forests.

Given our present understanding of the ecosystem, several aspects of forest management make it difficult to predict the long-term outcomes. First, the nature of the initial disturbance in intensively managed sites differs from natural disturbances, primarily fire and wind events. Intensive site preparation may nearly completely remove the native ground cover, such that herbaceous recovery depends on establishment from off-site seeds or from small residual populations. Plants of the longleaf system typically regenerate slowly, mostly from vegetative increases, and so the possible mechanisms for

recovery are not known. Additionally, species responses may differ among sites as a function of site quality. Moreover, managed stands may receive multiple treatments before harvested, e.g. fertilization or thinning for timber stand improvement or prescribed burning for fuel management. The cumulative effects of management practices are not well documented. Finally, forest development occurs over long time periods, and that time provides opportunities for stochastic events (e.g. wild fires, wind events, weather extremes) to intervene. The importance of stochastic events in the long-term trajectories of longleaf pine stand development, not surprisingly, are not known.

In summary, while site preparation can be an invaluable tool for establishing thriving pine stands, it can also have potentially severe consequences to pre-existing vegetation and can cause significant change in ground cover species composition and abundance. In addition, the effects of site preparation on ground layer vegetation composition may persist for long time periods. This study was designed to address both short- and long-term effects. Question #1 was addressed by a controlled field experiment to quantify short-term effects of selected site preparation methods on the most common hydric soil on Camp Lejeune. Question #2 was addressed by comparing the current conditions of maturing plantations to undisturbed pine stands in the mid-Atlantic coastal plain of North Carolina and relating compositional and structural changes to plantation management practices, environmental conditions, and disturbance and weather patterns.

3. Short-term effects of Longleaf Pine Plantation Establishment

This section contains detailed reports of results and accomplishments related to research objectives 1, 1a, 2, and 3. First the field experiment used to address these objectives is described. In subsequent sections, focused research literature reviews, sampling methods, analytical approaches, and results related to specific objectives are detailed. These objective specific sections are organized as for peer reviewed publication; if published, references will be given.

3.1 Field Experiment Overview: study sites, experimental design, and experimental treatments

Study Sites

The study was conducted on Marine Corps Base Camp Lejeune (34°7' N, 77°4' W), in Onslow County, North Carolina. Camp Lejeune is located within the Atlantic Coastal Flatlands Section of the Outer Coastal Plains Mixed Forest Province (Bailey, 1995). The climate is classified as warm humid temperate with an average annual temperature of 17.4 °C and an average annual precipitation of 145 cm (National Climate Data Center, Hofmann Forest Station, 34°5' N, 77°2' W). Nearly 30% of the soils on the MCB are considered hydric soils, and Leon fine sand is the most common hydric soil (9.5% of area) (USMC 2001). The study sites are located on the Leon series (sandy, siliceous, thermic Aeric Alaquod), poorly drained fine sands formed in sandy marine sediments. These soils are characterized by an A horizon of salt and pepper appearance and albic E horizons of light-gray to white sand, underlain by dark (Bh) spodic horizons. The spodic horizons, cemented by organic and iron compounds, are present in varying thickness of 15 to 25 cm and tend to be strongly cemented when dry (NRCS, 2003; Barnhill, 1992).

Natural vegetation on Leon sand in this area is longleaf pine savanna, consisting of longleaf pine overstories with herbaceous ground layers dominated by grasses and sedges, including wiregrass (*Aristida* spp.), bluestems (*Andropogon* spp., *Schizachyrium* spp.), panic grasses (*Panicum* spp., *Dichanthelium* spp.), and beak rushes (*Rhynchospora* spp.) (Frost, 2001). Additionally, the ground layer includes a diverse mix of forbs. With frequent fire, this site type is favorable for rare species such as roughleaf loosestrife (*Lysimachia asperulifolia* Poir.) and Venus flytrap (*Dionaea muscipula* Ellis). Common shrubs include *Ilex glabra* (L.) Gray, *Gaylussacia frondosa* (L.), and *Vaccinium* spp.

Areas selected for the study were previously dominated by mature stands of second growth longleaf pine. Overstories were harvested within two years prior to treatment application and any remaining vegetation was removed by shearing the sites.

Experimental design, treatments, and implementation

The experimental design is a randomized block with eight site preparation treatments replicated on 5 blocks, for a total of 40 experimental units. The location of blocks and

arrangement of experimental units are shown in Figure 3.1.1 and treatment assignments are given in Table 3.1.1. A total of 7 experimental blocks were initially established; however Blocks 4 and 6 were lost soon after establishment to wildlfire and misapplication of a chopping treatment. Results are based on five complete experimental blocks. The locations and treatment assignment of all 7 are included for the project record. Study treatments were randomly assigned to experimental units, which were approximately 0.4 ha in size and had 15 m buffers between plots to reduce treatment overlap. Eight site preparation treatments were applied in the summer of 2003, consisting of a check (no treatment applied), six combinations of two initial vegetation control treatments (chopping or herbicide) with three planting site conditions (flat [no additional treatment], mounding, or bedding), and a more intense treatment of chopping, herbicide, and bedding (Table 3.1.2). We refer to the treatments as follows: flat or check (F), chopping and flat (CF), herbicide and flat (HF), chopping and mounding (CM), herbicide and mounding (HM), chopping and bedding (CB), herbicide and bedding (HB), and chopping, herbicide, and bedding (CHB).

Vegetation control treatments were applied to the study sites first, followed by the planting site condition treatments. Treatment application was completed in August 2003. The chop treatment was done with a 2.4 m Lucas Drum Chopper, pulled by a TD15 Dresser crawler tractor (Cohen and Walker 2005). The herbicide treatment, made up of 0.70 kg/hectare of imazapyr (2-(4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl)-3-pyridinecarboxylic acid), and 0.56 kg/hectare of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid), was mixed and broadcast at a rate of 280 liters/hectare. Mounds approximately 1.2 m wide were created with a New Forest Technology™ custom mounding bucket on a Caterpillar 320BL excavator. The mounds were placed in rows as opposed to the random distribution that is often associated with mounding site preparation. A Rome 6 disc Bedding Harrow, with three discs on each side, was used for the bedding treatment to create beds 2.1 to 2.4 m wide. A prescribed burn in October/November 2003, following treatment application, removed remaining vegetation on all plots, which further prepared the sites for planting. Treatment plots were hand planted by contracted crews in December 2003 with container-grown seedlings grown from locally collected seed. Average root collar diameter of planted seedlings was 6.6 mm with a standard deviation of 1.2 mm.

All blocks were burned using strip head fires ignited by drip torch on either March 2, 7, or 14, 2006. Fires were ignited by drip torch using strip heads fires.

Table 3.1.1 Treatment assignments to experimental units by block. Experimental unit (EU) numbers correspond to labels in Figure 2.1 A-C. Half of Block 4 was lost to a wildfire before treatments were installed. In Block 6, the drum chopping treatment was mis- applied resulting in the loss of several treatments in this block. Analyses throughout the project were based on the 5 complete blocks: 1, 2, 3, 5, and 7. Treatment abbreviations are defined in the text.

Block	EU	Treatment	EU	Treatment
1	1	HB	5	CHB
	2	HF	6	CM
	3	F	7	CF
	4	CB	8	HM
2	1	CF	5	HM
	2	F	6	HF
	3	CB	7	HB
	4	CHB	8	CM
3	1	CB	5	HM
	2	CM	6	CF
	3	HF	7	HB
	4	F	8	CHB
4	1(3)**	CB	5	*
	2(5)	CF	6	*
	3(7)	CM	7	*
	4(8)	F	8	*
5	1	HF	5	HB
	2	HM	6	CF
	3	CM	7	CHB
	4	CB	8	F
6	1	HB	5	HM
	2	F	6	HF
	3	CHB	7	CHB
	4	CHB	8	CB
7	1	HF	5	HM
	2	F	6	CHB
	3	HB	7	CM
	4	CF	8	CB

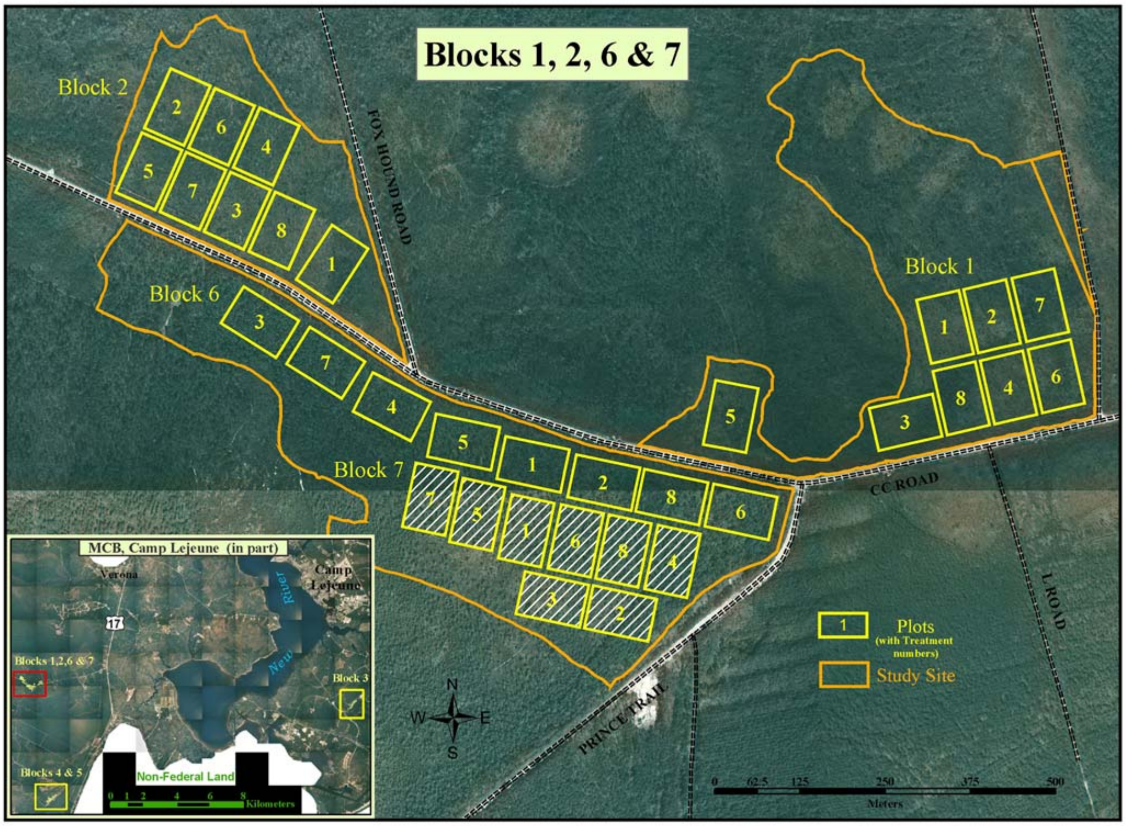
* EU lost to wild fire
** Original EU number in parenthesis; numbers reassigned after wildfire.

Table 3.1.2. Summary of site preparation treatments applied in the study.

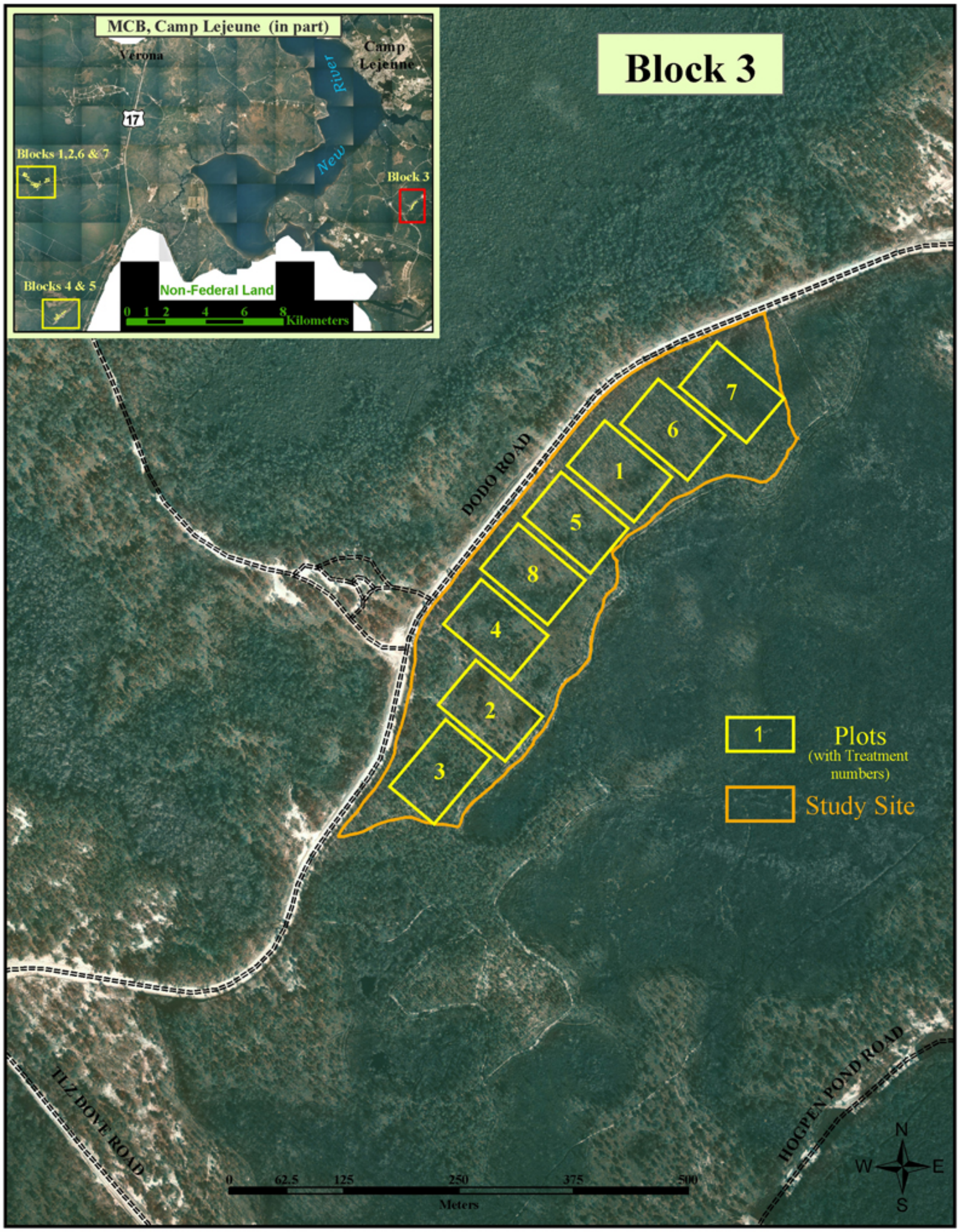
Treatment	Chopping	Herbicide	Flat	Mounding	Bedding
Flat (F) *			X		
Chopping/Flat (CF)	X		X		
Herbicide/Flat (HF)		X	X		
Chopping/Mounding (CM)	X			X	
Herbicide/Mounding (HM)		X		X	
Chopping/Bedding (CB)	X				X
Herbicide/Bedding (HB)		X			X
Chopping/Herbicide/Bedding (CHB)	X	X			X

* Check

Figure 3.1.1 (A-C). Map of study sites, blocks and experimental units. A. Blocks 1, 2, 6, and 7; B. Block 3; C. Blocks 4 and 5.

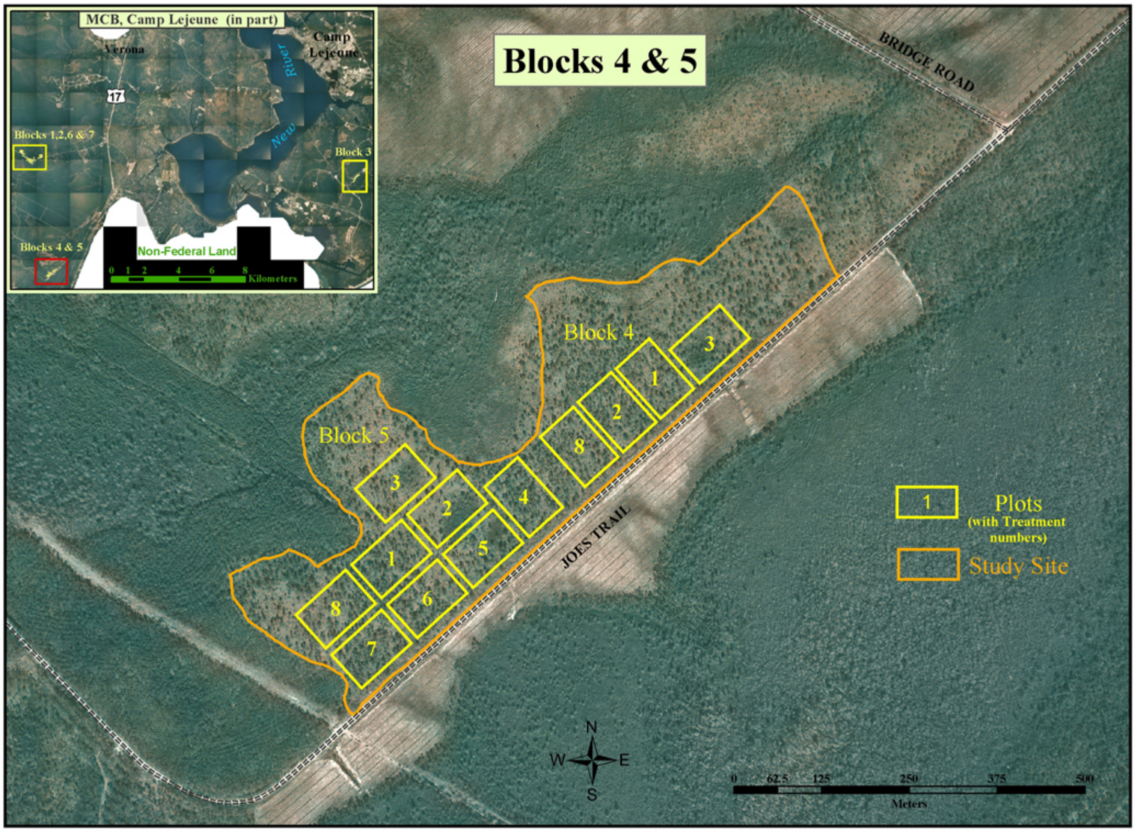


A. Blocks 1, 2, 6, and 7.



MCB, Camp Lejeune (in part)
Verona
Camp Lejeune
River
New
17
Blocks 1,2,6 & 7
Block 3
Blocks 4 & 5
Non-Federal Land
0 1 2 4 6 8 Kilometers
Block 3
DODO ROAD
7
6
1
5
8
4
2
3
1
Plots
(with Treatment numbers)
Study Site
TLZ DOVE ROAD
HOGPEN POND ROAD
N
W
E
S
0 62.5 125 250 375 500
Meters

B. Block 3.



C. Blocks 4 and 5. Block 4 has treatments 1, 2, 3, and 8 only; a wildfire and associated fire suppression activites destroyed the missing plots.

3.2 Treatment effects on longleaf pine mortality and growth through 20 months

[Contents of this section were extracted from Knapp, B.O., G.G. Wang, J.L. Walker, and S. Cohen. 2006. Forest Ecology and Management: 226:122-128.]

3.2.1 Introduction

Restoring the longleaf pine (*Pinus palustris* P. Miller) ecosystem is currently a major focus of land managers throughout the southeastern United States. Widespread reduction since European settlement has left longleaf pine occupying approximately three percent of its original range (Frost, 1993; Landers et al., 1995), largely due to land conversion and fire exclusion. Areas still containing longleaf pine may be maintained successfully with natural regeneration and frequent prescribed fire. However, the majority of the original range no longer contains longleaf pine in the overstory to provide seed and therefore requires artificial regeneration (Barnett, 1999).

Land managers in the southeastern United States frequently use site preparation in conjunction with artificial regeneration of southern pine species. Previous studies have demonstrated the effectiveness of various types of site preparation for increasing early growth of loblolly pine (*Pinus taeda* L.) and/or slash pine (*Pinus elliottii* Engelm.) (e.g. Burger and Pritchett, 1988; Nilsson and Allen, 2003; Rahman and Messina, 2006). For example, Knowe et al. (1992) reported that herbicides and chopping increased loblolly pine height (2.65 m) and diameter (4.47 cm) after four years of growth when compared to an untreated control (1.46 m, 1.45 cm, respectively). Moreover, studies have indicated that site preparation intensity is positively related to seedling growth (Nilsson and Allen, 2003). Burger and Pritchett (1988) compared the effects of low intensity site preparation (chopping) and high intensity site preparation (windrowing, disc harrowing, and bedding) on loblolly pine seedling response. After two growing seasons, seedling height and diameter were significantly greater on the high intensity treatment (79.9 cm and 2.33 cm, respectively) than on the low intensity treatment (68.5 cm and 1.41 cm, respectively). Barnett (1992) identifies well-prepared sites as a critical prerequisite for successful artificial regeneration of longleaf pine. Although limited to only a few studies, previous research has demonstrated the beneficial effects of mechanical treatments on survival and growth of planted longleaf pine seedlings (Croker, 1975; Croker and Boyer, 1975; Boyer, 1988). For instance, Boyer (1988) reported greater seedling survival three years after planting on sites treated with two passes of mechanical competition control (chop or harrow) (73% survival) when compared to sites with one mechanical pass (58% survival). Additionally, plots treated with herbicides shortly after planting resulted in 77% of seedlings in height growth after three years, compared to 58% of seedlings in height growth on untreated plots. The importance of competition control for longleaf pine establishment (Wahlenburg, 1946; Boyer, 1990) has prompted additional studies focused on understanding the effects of using herbicides for seedling release (e.g. Nelson et al., 1985; Creighton et al., 1987; Ramsey et al., 2003; Ramsey and Jose, 2004). Although the type of herbicide and method of application vary across published studies, competition control provided by herbicides typically results in improved seedling establishment. Haywood (2000) found that after three years of growth, 59% of surviving

seedlings had emerged from the grass stage on plots treated with herbicides and only 17% had emerged on untreated check plots. After five years, seedlings out of the grass stage were nearly twice as tall on herbicide plots as those on check plots, indicating potentially long term benefits for stand production.

Although longleaf pine naturally occurs on a range of site types that includes poorly drained flatwoods (Boyer, 1990), wet sites are often planted with faster growing pine species, and longleaf pine regeneration is commonly restricted to drier soils. Little is understood about how mechanical site preparation influences longleaf pine seedlings on wet sites. Studies on other southern pines have associated greater growth rates with improved drainage following mechanical treatments (e.g. bedding or mounding) on poorly drained sites (Outcalt, 1984; McKee and Wilhite, 1986; Haywood, 1987). For example, in a study in the flatwoods of Florida, Pritchett (1979) found that slash pines planted on bedded sites averaged 1.25 m taller than those planted on burn-only sites after eight growing seasons and suggested that increased drainage within the root zone was responsible for the growth difference. We would expect that improved drainage on wet sites would also benefit longleaf pine seedlings, although we are aware of no studies designed to evaluate the impact of mechanical treatments that alter soil conditions on longleaf pine seedling response.

The effectiveness of a site preparation treatment, in regard to seedling growth and survival, is typically determined by the magnitude of the target seedling's response; the treatment resulting in a higher growth rate or greater survival is considered the better treatment. However, effects of site preparations on seedling response are complex and vary with specific site, seasonal, and climatic conditions. Therefore, to implement site preparation most efficiently, it is important to understand the underlying mechanisms responsible for improving seedling growth and survival. According to Morris and Lowery (1988), two primary functions of site preparation include (1) manipulation of soil conditions and (2) competition control, and they discuss the benefit of separating the effects of each when evaluating site preparation treatments. However, many types of site preparation, especially mechanical treatments such as bedding and mounding, inherently alter both the immediate soil conditions and the abundance of competing vegetation. Therefore, it is necessary to directly quantify resource availability, soil conditions, and abundance of competing vegetation when identifying primary effects of a site preparation treatment.

This study was designed to investigate the effectiveness of common site preparations for use in longleaf pine regeneration on poorly drained soils by relating seedling response to direct measurements of microsite conditions. Our specific objectives were to: (1) quantify soil conditions (moisture and temperature), abundance of competing vegetation, and light availability following low to medium intensity site preparation treatments, and (2) determine relationships between seedling survival/growth and the measured microsite conditions.

3.2.2 Data collection and analytical methods

Data collection

In May 2004, a census of all seedlings was used to determine survival rates for each measurement plot after six months of growth. Seedlings were classified as 'alive' if any of the foliage was green. Additionally, a sub-sample of 45 seedlings was randomly selected and permanently marked for repeated measurement on each experimental unit. Seedlings were selected by randomly determining a seedling within the first planted row and selecting the other seedlings at a set interval to evenly distribute them throughout the plot, based on the number of rows per plot and approximate number of seedlings per row. Survival through August 2005 was monitored on the sub-sample of 45 seedlings per experimental unit during every subsequent growth measurement period.

Growth measurements were repeated for each sub-sampled seedling in May, June, July, August, and December 2004, and May and August 2005. Root collar diameter, considered the best way to monitor growth while the seedling remains in the grass stage, was measured using digital calipers. Care was taken not to cut the cambium of the seedlings. The distance from the soil surface to the base of the terminal bud was measured, and seedlings were considered to be in height growth when the terminal bud reached a height of 15 cm (Nelson et al. 1985, Boyer 1988).

Data analysis

Seedling survival from May 2004 through August 2005 was monitored for only the 45 sub-sampled seedlings during each of the growth measurement periods. Overall seedling survivorship was calculated for each measurement period by applying the survival rates from the sub-sampled seedlings to the number of living seedlings at the start of May 2004, as determined by the complete census. Because the sub-sampled seedlings were randomly selected from only those seedlings with proper planting depth, our survival rates would likely be an overestimation of the actual survival rates for the entire population. However, a complete survey of seedling survivorship after one year (Cohen and Walker 2005) found survival to differ from our estimate by only 1.2 percent. A paired t-test, by matching experimental units, indicated there was no significant difference in survival rates from the two estimates ($p = 0.402$). Therefore, we feel confident in using the survival rates calculated from the sub-sampled seedlings in the analysis.

Repeated measures analysis of variance was used to examine the treatment effects on seedling survival and root collar diameter, and changes in seedling survival and root collar diameter over time (from May 2004 to August 2005). Seedling survival and root collar diameter at 12 and 20 months after planting were also analyzed using analysis of variance, with the eight treatment combinations as factors, and a 3 x 2 factorial analysis of variance without the intense treatment (CHB) and check (F). The first factor in the factorial analysis (planting site condition) had three levels: flat (i.e., no treatment), mounding, and bedding. The second factor (vegetation control) had two levels: chopping and herbicide. We used analysis of variance, followed by pairwise comparisons, to draw

conclusions about each treatment combination and specific site preparation factor (planting site condition or vegetation control).

After 20 months of growth, the number of seedlings in height growth (i.e., emerged from the grass stage) per sub-sample was calculated as a percentage of live seedlings measured. The data were log-transformed to improve normality (Krebs 1999):

$$Y = Log(X + 1)$$

where Y is the transformed data and X is the original percentage. Analysis of variance followed by pairwise comparisons was used to determine differences among the eight treatments. A 3 x 2 factorial analysis of variance was also conducted to determine the effect of each specific factor. Additionally, the root collar diameter of each seedling in height growth was noted one measurement period prior to emergence from the grass stage. Treatment differences in root collar diameter prior to emergence were determined using analysis of variance. We used SAS (SAS Institute 2003) and SYSTAT (SYSTAT Software Inc. 2002) software for the analysis. Unless otherwise stated, the level of statistical significance was set at $\alpha = 0.05$.

3.2.3 Results

Seedling survival

Although seedling survival significantly decreased over time ($p < 0.001$), no differences in survival were detected among the eight treatments ($p = 0.566$). There was no interaction between treatment and time ($p = 0.753$). First-year survival (through December 2004) ranged from 68 percent on HM to 75 percent on CB, with an overall mean of 70 percent (Figure 3.2.1). At 20 months after planting (August 2005), seedling survival averaged 59 percent, with the lowest survival on HB (57 percent) and the highest survival on CB (65 percent). Based on factorial analysis of variance, there was no interaction between planting site condition and competition control treatment at either 12 months ($p = 0.559$) or 20 months ($p = 0.645$). Neither planting site condition nor vegetation control treatment affected seedling survival at 12 or 20 months after planting ($p \geq 0.280$) (Table 3.2.1).

Root collar diameter growth

Root collar diameters increased over time ($p < 0.001$) and differed among treatments ($p < 0.001$). There was an interaction between treatment and time ($p < 0.001$) (Figure 3.2.2). When analyzed for each measurement period, treatment differences were detected only eight (August 2004) or more (December 2004, May 2005, August 2005) months after planting ($p \leq 0.003$). After 12 months of growth, HB and CHB resulted in similar root collar diameters and were both greater than F, CF, and CM (Figure 3.2.2, Table 3.2.2). Additionally, HB increased root collar growth when compared to HM and HF. The least amount of growth was on CF, which was lower than all other treatments besides F. After 20 months of growth, CHB resulted in greater root collar diameter growth than all other treatments except HB; the least amount of growth was once again on F and CF.

Based on factorial analysis of variance, both planting site condition and vegetation control treatment affected root collar diameter ($p \leq 0.002$), and there was no significant interaction between them at 12 months ($p = 0.169$) or 20 months ($p = 0.983$) after planting. After 12 months of growth, bedding resulted in greater root collar diameter than either mounding ($p = 0.004$) or flat treatments ($p < 0.001$), and no difference ($p = 0.214$) was found between mounding and flat treatments (Table 3.2.3). The herbicide treatment resulted in greater growth than chopping ($p < 0.001$). At 20 months of growth, bedding and mounding were similar ($p = 0.194$), and both resulted in more growth than the flat treatment ($p \leq 0.002$). The herbicide treatment yielded more growth than the chop treatment ($p = 0.002$).

Height growth

After 20 months, the percentage of seedlings in height growth (i.e., terminal bud at least 15 cm above soil surface) differed among the eight treatments ($p < 0.001$). CHB had more seedlings in height growth than CB, HF, CF, and F (Table 3.2.2). Additionally, HB and HM had significantly more seedlings in height growth than F and CF, in which no seedlings had yet emerged from the grass stage.

Based on the factorial analysis of variance, both planting site condition and vegetation control treatment affected the number of seedlings in height growth ($p < 0.016$), although no interaction was found between them ($p = 0.972$). Bedding and mounding were similar ($p = 0.565$) and were both greater than the flat treatments ($p \leq 0.030$) with respect to the percentage of seedlings in height growth. The herbicide treatment resulted in a higher percentage of seedlings in height growth than the chop treatment ($p = 0.016$) (Table 3.2.3).

For seedlings emerged from the grass stage, there were no treatment differences in root collar diameter measured prior to height growth initiation ($p = 0.348$). The root collar diameters of these seedlings ranged from 22.4 mm (HM) to 24.8 mm (HF), with a mean of 23.3 mm and standard deviation of 2.8 mm across all treatments.

3.2.4 Discussion

We did not find any treatment effects on seedling survival. The overall mean survival rates of 70 percent after one year and 59 percent after 20 months found in our study are within the range of survival rates previously reported. For example, Loveless et al. (1989) reported average first-year survival at 56 percent, Ramsey et al. (2003) reported a first-year survival rate of 75 percent on a well-drained site in Florida, and Boyer (1988) reported a survival rate of 67 percent on a poorly drained site after three years of growth. Barnett et al. (1990) recommended a minimum of 300 seedlings per acre after the first year. Our study sites were planted at a density of approximately 550 seedlings per acre, which would leave 373 to 413 seedlings per acre (depending on treatment) after the first year of growth. Therefore, all site preparation treatments resulted in satisfactory survival for longleaf pine regeneration on these poorly drained, sandy sites.

Although site preparation treatments tested in our study did not affect seedling survival up to 20 month after planting, these treatments had significant effects on seedling growth. Among the three planting site conditions, bedding and mounding positively affected root collar diameter and percentage of seedlings in height growth after 20 months of growth. Compared to flat sites, bedding and mounding improve growing conditions, perhaps resulting from increased soil aeration and improved surface drainage as others have suggested (Pritchett 1979, McKee and Wilhite 1986, Haywood 1987, Sutton 1993). Additionally, the disturbance created by the treatments appears to reduce competing vegetation, which has long been considered important for improving longleaf pine growth (Wahlenburg 1946).

Previous studies have demonstrated the potential of herbicide use for increasing growth of longleaf pine seedlings (Nelson et al. 1985, Haywood 2000, Ramsey et al. 2003). For example, herbicide use resulted in as many as twice the number of seedlings in height growth after two years when compared to a check (Nelson et al. 1982). In our study, the herbicide-only treatment (HF) resulted in greater root collar growth than CF or the check (F), although there were no significant differences in the percentage of seedlings in height growth. However, seedlings had begun height growth on HF, indicating that the treatment is superior to CF and F, in which neither had any seedlings in height growth.

Overall, the chop treatment used in this study appeared to be essentially ineffective for increasing growth. Studies on the effect of chopping on longleaf pine are limited to Boyer (1988), in which multiple passes of a chopper increased growth after two years when compared to a single pass. A single pass, as seen in the current study, may not provide adequate competition control to improve seedling growth. Previous studies have also found chopping to be inferior for competition control when compared to other mechanical treatments. For example, Miller (1980) found shearing and windrowing caused a 55 % reduction in standing vegetation after two years when compared to chopping. Although chopping initially reduces competing vegetation, its benefit is usually short-lived due to rapid vegetation regrowth. For example, in the Boyer study (1988), the effects of chopping on seedling growth were no longer significant after the third year of growth.

Our results indicated that the effects of planting site condition and competition control were additive. We found that CHB, HB and HM were the treatment combinations that most benefited seedling growth. The CHB treatment included both types of competition control and was the most intense treatment used in the study. Site preparation intensity is considered to be positively correlated with longleaf pine growth, especially when used for competition control (Boyer 1983). However, because HB was similar to CHB in root collar diameter growth and percentage of seedlings in height growth, the addition of the chop treatment to HB may not be necessary for maximizing longleaf pine growth.

We also investigated the idea that different treatments may influence the timing of height growth initiation. Among the seedlings that had begun height growth, we found that root collar diameters prior to emergence were confined to a narrow range (22.4 – 24.8 mm, mean of 23.6 mm). This result supports the idea that longleaf pine seedlings begin height

growth when the root collar approaches 25 mm (Boyer 1990). The treatments used in this study affected the root collar diameter, which in turn affected grass stage emergence. However, the treatments did not appear to have any other influence on height growth initiation other than that associated with effects on root collar diameter.

3.2.5. Management Implications

Site preparation treatments appear to be an appropriate technique for land managers who wish to rapidly establish planted longleaf pine seedlings on poorly drained, sandy sites in the southeastern United States. Because the treatments used in this study had no impact on early seedling survival of planted longleaf pine seedlings, decisions on treatment application should be based on the effects of site preparation treatments on seedling growth. We found that root collar diameter was directly related to height growth initiation, and therefore treatments maximizing root collar diameter growth would also shorten time in the grass stage. Based on seedling growth at 20 months after planting, we found bedding and mounding to be the best planting site conditions and herbicide to be the best vegetation control treatment. To improve early seedling growth, bedding or mounding in combination with herbicide treatments should be applied when planting longleaf pine seedlings. Chopping may also be used in combination with bedding and herbicide to provide the maximum benefit. These recommended site preparation treatments, if in accordance with other management objectives, can be a valuable tool for forest managers interested in artificially regenerating longleaf pine on poorly drained sites within the coastal plain of the southeastern United States.

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Table 3.2.1. Factorial analysis of mean seedling survival rates at 12 months and 20 months after planting. Means with the same superscript letter indicate no significant difference ($\alpha = 0.05$).

Treatment	Mean Survival % at 12 Months	Mean Survival % at 20 Months
Flat	69.6^{a}	59.4^{a}
Mounding	68.2^{a}	57.6^{a}
Bedding	72.7^{a}	60.8^{a}
p-value	**0.431**	**0.689**
Chopping	71.6^{a}	60.9^{a}
Herbicide	68.8^{a}	57.6^{a}
p-value	**0.332**	**0.280**

Table 3.2.2. Root collar diameter means for each treatment through 12 and 20 months after planting and percentage of seedlings in height growth for each treatment at 20 months after planting. Means are followed by standard deviation in parenthesis. Means with the same superscript letter indicate no significant difference ($\alpha = 0.05$).

	Root Collar Diameter (mm)				Percentage in Height Growth**	
Treatment*	12 Months		20 Months		20 Months	
F	13.2^{de}	(2.7)	15.1^{fg}	(3.8)	0.0^{c}	(0.0)
CF	13.0^{e}	(2.8)	15.0^{g}	(3.8)	0.0^{c}	(0.0)
HF	14.9^{bc}	(3.5)	16.6^{ef}	(4.9)	4.3^{bc}	(7.2)
CM	14.1^{cd}	(3.4)	17.8^{de}	(5.7)	5.9^{abc}	(5.2)
HM	14.9^{bc}	(3.8)	19.8^{bc}	(6.2)	11.4^{ab}	(8.0)
CB	15.2^{abc}	(3.8)	18.6^{cd}	(5.4)	5.0^{bc}	(8.2)
HB	16.1^{a}	(4.3)	21.2^{ab}	(6.8)	11.3^{ab}	(13.0)
CHB	15.6^{ab}	(4.1)	22.1^{a}	(7.4)	19.0^{a}	(10.2)

*Treatments are defined in Table 3.1.2.
**Analysis was conducted based on log-transformation.

Table 3.2.3. Factorial analysis of least square means of root collar diameter at 12 months and 20 months after planting and percentage of seedlings in height growth 20 months after planting. Means with the same superscript letter indicate no significant difference ($\alpha = 0.05$).

	Root Collar Diameter (mm)		Percentage in Height Growth*
Treatment	12 Months	20 Months	20 Months
Flat	14.0^{b}	15.7^{b}	2.2^{b}
Mounding	14.5^{b}	18.6^{a}	8.6^{a}
Bedding	15.6^{a}	19.8^{a}	8.1^{a}
p-value	**<0.001**	**<0.001**	**0.003**
Chopping	14.1^{b}	17.0^{b}	3.6^{b}
Herbicide	15.3^{a}	19.0^{a}	9.0^{a}
p-value	**<0.001**	**0.002**	**0.016**

*Analysis was conducted based on log-transformation.

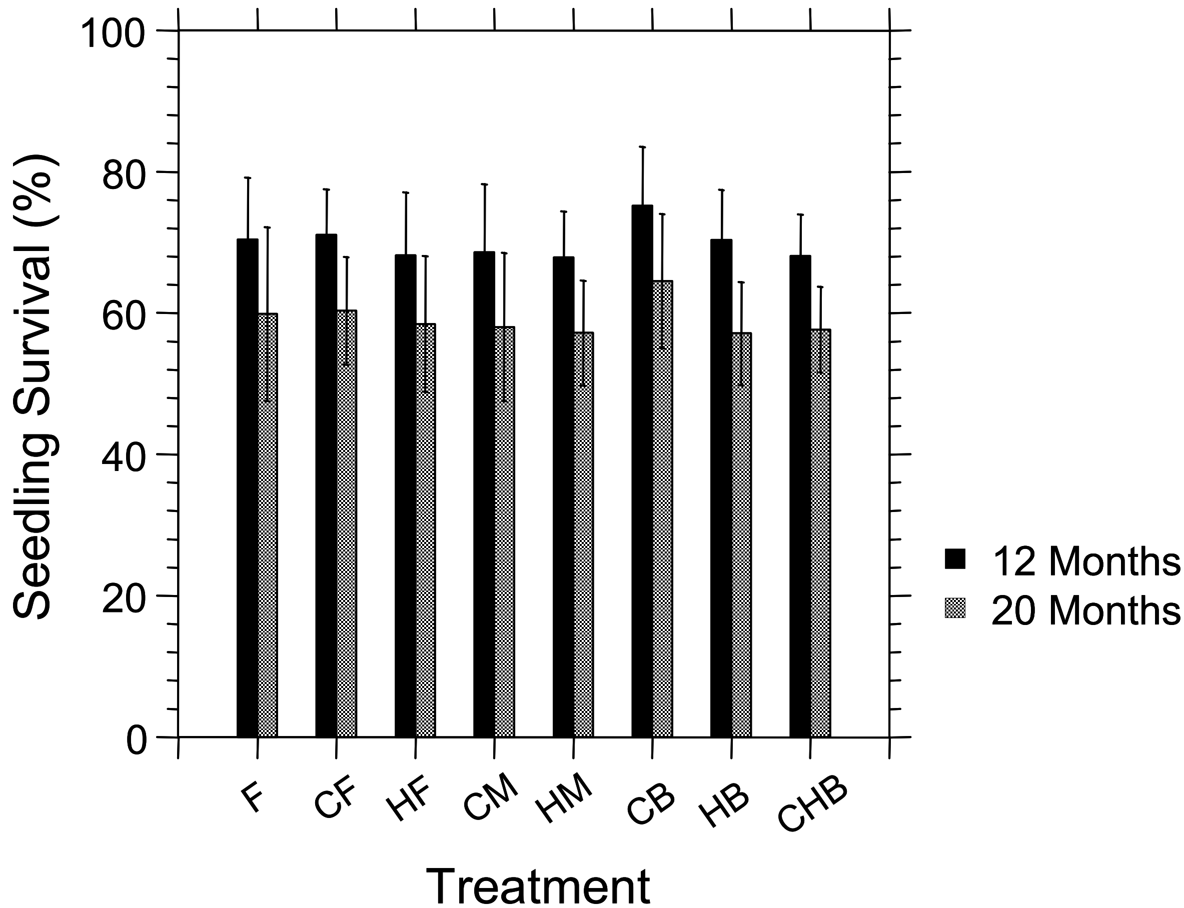

Figure 3.2.1. Survival rates of planted longleaf pine seedlings by treatment at 12 months and 20 months after planting. Error bars are standard errors. Treatments are defined in Table 3.1.2.

*

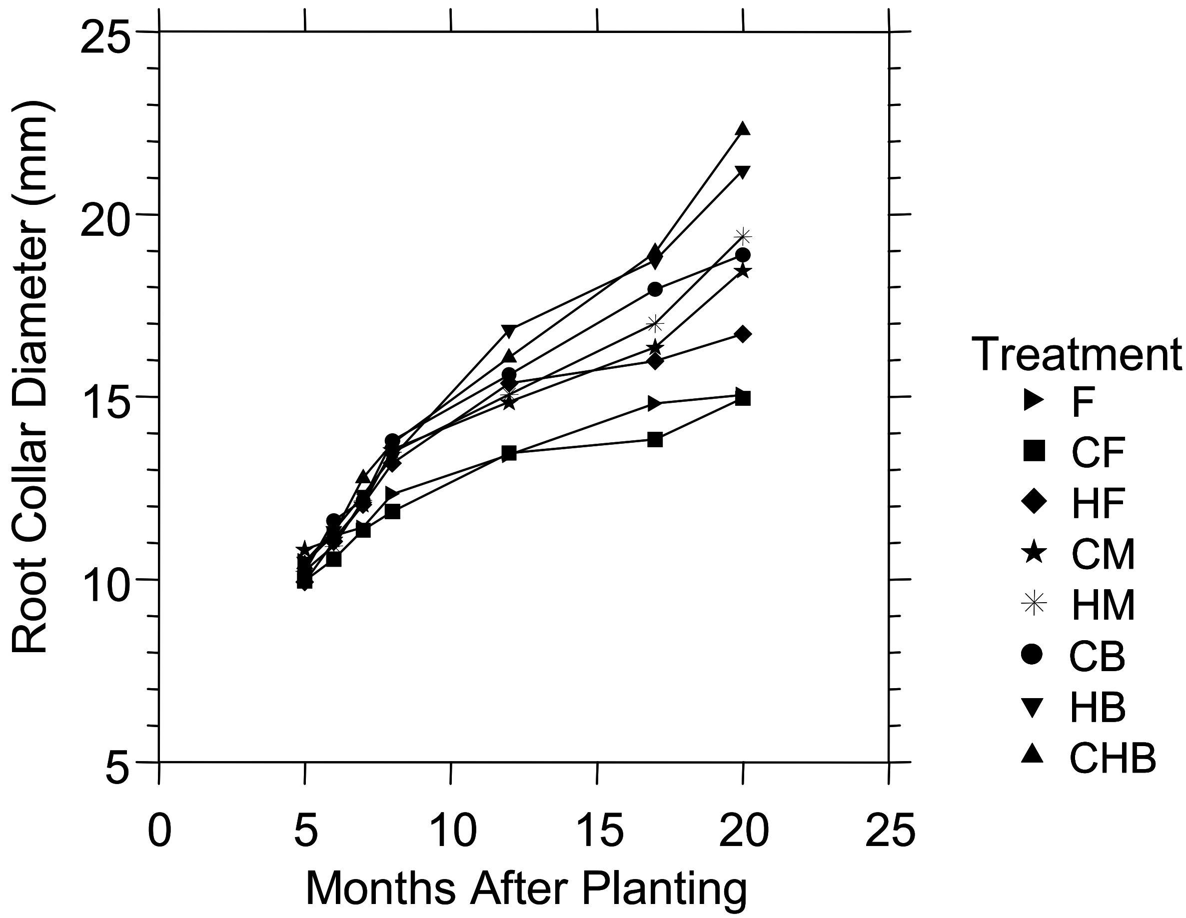

Figure 3.2.2. Root collar diameter (mm) by treatment during each measurement period from 5 months after planting (May 2004) until 20 months after planting (August 2005). Treatments are defined in Table 3.1.2.

3.3 Relationship of longleaf pine seedling survival and growth to microsite conditions altered by site preparation treatments

[This section is extracted from Knapp, B.O., G.G. Wang, and J.L. Walker. 2008. Relating the survival and growth of planted longleaf pine seedlings to mircosite constions altered by site preparation treatments. Forest Ecology and Management 255:3768-3777.]

3.3.1 Introduction

Restoring the longleaf pine (*Pinus palustris* P. Miller) ecosystem is currently a major focus of land managers throughout the southeastern United States. Widespread reduction since European settlement has left longleaf pine occupying approximately three percent of its original range (Frost, 1993; Landers et al., 1995), largely due to land conversion and fire exclusion. Areas still containing longleaf pine may be maintained successfully with natural regeneration and frequent prescribed fire. However, the majority of the original range no longer contains longleaf pine in the overstory to provide seed and therefore requires artificial regeneration (Barnett, 1999).

Land managers in the southeastern United States frequently use site preparation in conjunction with artificial regeneration of southern pine species. Previous studies have demonstrated the effectiveness of various types of site preparation for increasing early growth of loblolly pine (*Pinus taeda* L.) and/or slash pine (*Pinus elliottii* Engelm.) (e.g. Burger and Pritchett, 1988; Nilsson and Allen, 2003; Rahman and Messina, 2006). For example, Knowe et al. (1992) reported that herbicides and chopping increased loblolly pine height (2.65 m) and diameter (4.47 cm) after four years of growth when compared to an untreated control (1.46 m, 1.45 cm, respectively). Moreover, studies have indicated that site preparation intensity is positively related to seedling growth (Nilsson and Allen, 2003). Burger and Pritchett (1988) compared the effects of low intensity site preparation (chopping) and high intensity site preparation (windrowing, disc harrowing, and bedding) on loblolly pine seedling response. After two growing seasons, seedling height and diameter were significantly greater on the high intensity treatment (79.9 cm and 2.33 cm, respectively) than on the low intensity treatment (68.5 cm and 1.41 cm, respectively).

Barnett (1992) identifies well-prepared sites as a critical prerequisite for successful artificial regeneration of longleaf pine. Although limited to only a few studies, previous research has demonstrated the beneficial effects of mechanical treatments on survival and growth of planted longleaf pine seedlings (Croker, 1975; Croker and Boyer, 1975; Boyer, 1988). For instance, Boyer (1988) reported greater seedling survival three years after planting on sites treated with two passes of mechanical competition control (chop or harrow) (73% survival) when compared to sites with one mechanical pass (58% survival). Additionally, plots treated with herbicides shortly after planting resulted in 77% of seedlings in height growth after three years, compared to 58% of seedlings in height growth on untreated plots. The importance of competition control for longleaf pine establishment (Wahlenburg, 1946; Boyer, 1990) has prompted additional studies focused on understanding the effects of using herbicides for seedling release (e.g. Nelson et al., 1985; Creighton et al., 1987; Ramsey et al., 2003; Ramsey and Jose, 2004).

Although the type of herbicide and method of application vary across published studies, competition control provided by herbicides typically results in improved seedling establishment. Haywood (2000) found that after three years of growth, 59% of surviving seedlings had emerged from the grass stage on plots treated with herbicides and only 17% had emerged on untreated check plots. After five years, seedlings out of the grass stage were nearly twice as tall on herbicide plots as those on check plots, indicating potentially long term benefits for stand production.

Although longleaf pine naturally occurs on a range of site types that includes poorly drained flatwoods (Boyer, 1990), wet sites are often planted with faster growing pine species, and longleaf pine regeneration is commonly restricted to drier soils. Little is understood about how mechanical site preparation influences longleaf pine seedlings on wet sites. Studies on other southern pines have associated greater growth rates with improved drainage following mechanical treatments (e.g. bedding or mounding) on poorly drained sites (Outcalt, 1984; McKee and Wilhite, 1986; Haywood, 1987). For example, in a study in the flatwoods of Florida, Pritchett (1979) found that slash pines planted on bedded sites averaged 1.25 m taller than those planted on burn-only sites after eight growing seasons and suggested that increased drainage within the root zone was responsible for the growth difference. We would expect that improved drainage on wet sites would also benefit longleaf pine seedlings, although we are aware of no studies designed to evaluate the impact of mechanical treatments that alter soil conditions on longleaf pine seedling response.

The effectiveness of a site preparation treatment, in regard to seedling growth and survival, is typically determined by the magnitude of the target seedling's response; the treatment resulting in a higher growth rate or greater survival is considered the better treatment. However, effects of site preparations on seedling response are complex and vary with specific site, seasonal, and climatic conditions. Therefore, to implement site preparation most efficiently, it is important to understand the underlying mechanisms responsible for improving seedling growth and survival. According to Morris and Lowery (1988), two primary functions of site preparation include (1) manipulation of soil conditions and (2) competition control, and they discuss the benefit of separating the effects of each when evaluating site preparation treatments. However, many types of site preparation, especially mechanical treatments such as bedding and mounding, inherently alter both the immediate soil conditions and the abundance of competing vegetation. Therefore, it is necessary to directly quantify resource availability, soil conditions, and abundance of competing vegetation when identifying primary effects of a site preparation treatment.

This study was designed to investigate the effectiveness of common site preparations for use in longleaf pine regeneration on poorly drained soils by relating seedling response to direct measurements of microsite conditions. Our specific objectives were to: (1) quantify soil conditions (moisture and temperature), abundance of competing vegetation, and light availability following low to medium intensity site preparation treatments, and (2) determine relationships between seedling survival/growth and the measured microsite conditions.

3.3.2 Data collection and analysis

In May 2004, a sub-sample of 45 seedlings was identified in each experimental unit by randomly determining a seedling within the first planted row and selecting the other seedlings at a regular interval to distribute selected seedlings evenly throughout the plot. The sample interval was based on the number of rows per plot and approximate number of seedlings per row. This sub-sample of seedlings was used to monitor seedling survival and growth throughout the 2004 and 2005 growing seasons (Knapp et al., 2006). Microsite conditions measured during 2004 and 2005 included soil moisture at a 6 cm depth, soil temperature at a 15 cm depth, soil surface temperature, percent full sunlight at the seedling level, and percent cover of vegetation surrounding selected seedlings.

Soil moisture at 6 cm, soil temperature at 15 cm, and soil surface temperature were measured adjacent to 10 seedlings randomly selected from the measurement sub-sample in each experimental unit. To reduce variability from weather conditions, all measurements within a single block were taken within a two-hour period just after noon. Soil moisture was measured with a Theta Probe Moisture Meter (Delta-T Devices, Ltd.), which was calibrated with soil samples from the study sites. Soil temperatures at the surface and a depth of 15 cm were recorded using digital thermometers at locations directly east of soil moisture measurements. Means for each variable were calculated for the 2004 and 2005 growing seasons based on measurements taken in June, July, and August 2004, and May and August 2005.

Percent full sunlight reaching each selected seedling was calculated by measuring photosynthetically active radiation (PAR) once during each growing season (August 2004 and August 2005) with an AccuPAR model LP-80 ceptometer (Decagon Devices, Inc.). Two readings were taken at the level of each seedling and the mean was recorded. Care was taken to avoid the shadow of selected seedlings. Similarly, two readings were taken approximately one meter above each selected seedling and the mean was recorded for an open sky measurement. Open sky readings were taken immediately following seedling level readings to maintain consistent light conditions. On check treatments, vegetation was often tall enough to require the open sky reading to be taken higher than one meter above the seedlings, but otherwise did not interfere with the measurements. Due to a lack of uniformity on cloudy days, readings were taken under clear sky conditions. Percent full sunlight was calculated with equation (1):

$$Y = (PAR_{below}/PAR_{above})*100 \tag{1}$$

where Y is percent full sunlight, PAR_{below} is the average seedling level light reading, and PAR_{above} is the average open sky light reading for each seedling.

Competing vegetation immediately surrounding 15 seedlings selected from the sub-sample on each experimental unit, including the 10 associated with soil moisture/temperature measurements, was quantified during August 2004 and August 2005. Approximately 1 m^2 circular plots (0.6 m radius) were established around selected seedlings to determine percent cover of vegetation within each sampling plot. Visual estimates of percent cover were made for total vegetation and the following plant groups:

ferns, forbs, shrubs, and graminoids. The cover classes used were modified from the North Carolina Vegetation Survey (Peet et al., 1998), as follows: (1) < 1%, (2) 1-2 %, (3) 3-5 %, (4) 6-10 %, (5) 11-25 %, (6) 26-50 %, (7) 51-75 %, (8) 76-90 %, (9) 91-100 %.

For each growing season (2004 and 2005), means of soil moisture at 6 cm, soil temperature at 15 cm, soil surface temperature, percent full sunlight, and percent cover of total vegetation and each vegetation group were analyzed with analysis of variance using PROC GLM in SAS (SAS Institute, 2003). The analysis was conducted in two ways: 1) all eight treatments were used as factors to determine differences among the treatment combinations, and 2) the treatment with both chopping and herbicide (CHB) and the check (F) were disregarded, creating a 3 x 2 factorial analysis of variance to distinguish between effects of vegetation control treatments (chopping or herbicide) and of the planting site conditions (flat planting, mounding, or bedding). Significant differences among treatments were determined using Tukey's LSD post-hoc test. When necessary, transformations were used to normalize data prior to analysis.

We used regression analysis to determine relationships between dependent variables (seedling mortality and root collar diameter) and the environmental variables measured in each growing season (soil moisture at 6 cm, soil temperature at 15 cm, soil surface temperature, percent full sunlight, and total percent cover). Because percent full sunlight and vegetation cover were measured in August 2004 and 2005 (8 and 20 months after planting, respectively), we used seedling mortality and root collar diameter measurements from 8 and 20 months after planting for the regression analysis. Scatterplots and linear regression were used to determine the type and strength of relationships between the dependent variables and each environmental variable. Additionally, we used multiple regression analysis with all independent variables to create predictive models for seedling mortality and root collar diameter after 20 months of growth (August 2005 data). Percent cover of separate plant groups was used to create the predictive models, and square root transformations were used to normalize the data for each plant group. Significant variables were determined using Mallow's Cp method of variable selection (Mallows, 1973; Ott and Longnecker, 2001), and many models were tested to determine the best fit. We used SAS (SAS Institute, 2003) and SYSTAT (SYSTAT Software Inc., 2002) software for the analyses, with a level of statistical significance at $\alpha = 0.05$.

3.3.3 Results

Soil moisture and temperature

One-way ANOVA indicated that there were significant differences in the amount of moisture within the upper 6 cm of the soil among the eight treatment combinations (Table 3.3.1). In 2004, HF had greater soil moisture than any other treatment, followed by F and CF ($F_{7, 28} = 12.1$, $p < 0.001$). In 2005, HF, F, and CF had significantly more moisture in the soil than any of the other treatments ($F_{7, 28} = 7.3$, $p < 0.001$). The 3 x 2 factorial ANOVA indicated there was no significant interaction between planting site condition and vegetation control treatments in 2004 ($F_{2, 20} = 1.9$, $p = 0.175$) or 2005 ($F_{2, 20} = 2.7$, $p = 0.093$). Among the planting site conditions, bedding and mounding reduced soil moisture

by at least 10 percent when compared to flat treatments in both 2004 and 2005 (3.2.2). Between the vegetation control treatments, the herbicide treatment resulted in more soil moisture than the chop treatment in 2004 ($F_{1, 20} = 4.7$, $p = 0.043$), although there was no difference in 2005 ($F_{1, 20} = 0.0$, $p = 0.997$).

Soil temperature at 15 cm also significantly differed among the treatment combinations in both 2004 ($F_{7, 28} = 6.8$, $p < 0.001$) and 2005 ($F_{7, 28} = 10.3$, $p < 0.001$) (3.3.1). The greatest temperatures in 2004 were on CM and HM, while the lowest temperature was on the check (F). In 2005, the same trend continued, with the greatest temperature on CM, HM, and CB, and the lowest on F. There was no significant interaction between planting site condition and vegetation control treatments in 2004 ($F_{2, 20} = 0.3$, $p = 0.730$) or 2005 ($F_{2, 20} = 2.2$, $p = 0.134$). In 2005, mounded sites had the greatest temperatures among planting site conditions, although bedding also raised temperatures when compared to flat sites (Table 3.3.2). There were no differences in soil temperature between chopping and herbicide treatments in 2004 ($F_{1, 20} = 0.5$, $p = 0.505$) or 2005 ($F_{1, 20} = 1.1$, $p = 0.298$).

There were no significant differences among the eight treatment combinations for 2004 soil surface temperature measurements ($F_{7, 28} = 1.7$, $p = 0.154$) (Table 3.3.1). In 2005 ($F_{7, 28} = 3.3$, $p = 0.011$) CHB resulted in the greatest surface temperature and F resulted in the lowest temperature. The factorial analyses from 2004 and 2005 (3.3.2) indicated no significant differences among the planting site conditions ($F_{2, 20} = 0.9$, $p = 0.424$ and $F_{2, 20} = 2.0$, $p = 0.168$, respectively) or vegetation control treatments ($F_{1, 20} = 0.3$, $p = 0.607$ and $F_{1, 20} = 0.0$, $p = 0.956$, respectively).

Light and total competition

Availability of sunlight was significantly different among the eight treatment combinations in both 2004 ($F_{7, 28} = 6.6$, $p < 0.001$) and 2005 ($F_{7, 28} = 7.8$, $p < 0.001$). In 2004, seedlings on F received less sunlight than any other treatment (Figure 3.3.1A). The check also received the least amount of sunlight in 2005, although CF, CB, and HF received significantly less sunlight than HM, CM, HB, and CHB. There was no significant interaction between planting site condition and vegetation control treatment in 2004 ($F_{2, 20} = 1.1$, $p = 0.338$) or 2005 ($F_{2, 20} = 2.4$, $p = 0.121$). Planting site condition had a significant treatment effect in both years ($F_{2, 20} = 3.9$, $p = 0.024$ and $F_{2, 20} = 10.0$, $p = 0.001$, respectively), with the mounded treatments receiving more sunlight than flat treatments and the bedded treatments not different from flat planting or mounding (Table 3.3.3). The vegetation control treatments did not significantly differ in 2004 ($F_{1, 20} = 0.1$, $p = 0.762$), but the herbicide treatments resulted in more sunlight at the seedling level in 2005 ($F_{1, 20} = 5.7$, $p = 0.027$).

Significant treatment differences in total percent cover of surrounding vegetation are displayed by treatment combination in 3.3.1B for 2004 ($F_{7, 28} = 40.4$, $p < 0.001$) and 2005 ($F_{7, 28} = 17.1$, $p < 0.001$). In both years, the greatest abundance of vegetation was on F and CF, with the least on HM, HB, and CHB in 2004, and CM and HM in 2005. The factorial analysis indicated no significant interaction between the planting site condition and vegetation control treatment in 2004 ($F_{2, 20} = 1.9$, $p = 0.178$) or 2005 ($F_{2, 20} = 1.1$, $p =$

0.268). Among the planting site conditions, flat treatments had the greatest percent cover of surrounding vegetation and mounded treatments had the least (Table 3.3.3). Herbicides reduced abundance of surrounding vegetation more than chopping in 2004 and 2005 ($F_{1, 20} = 51.8$, $p < 0.001$ and $F_{1, 20} = 5.0$, $p = 0.036$, respectively).

Vegetation by groups

Among the treatment combinations, there were significant differences in forb ($F_{7, 28} = 9.8$, $p < 0.001$), shrub ($F_{7, 28} = 24.5$, $p < 0.001$), and graminoid ($F_{7, 28} = 11.1$, $p < 0.001$) cover in 2004, and shrub ($F_{7, 28} = 9.9$, $p < 0.001$) and graminoid ($F_{7, 28} = 3.5$, $p = 0.008$) cover in 2005 (3.2.2). Only shrubs and graminoids provided greater than 10 percent cover on any treatment combination. In both years, the greatest amount of shrub cover occurred on F and CF. Similarly, 2004 graminoid cover was greatest on F and CF and least on HB, CHB, and HM. By the second growing season, graminoid cover was highest on CF, HF, HB, and CHB and in the lowest abundance on CM and HM. The factorial analysis in each growing season indicated no significant interactions between planting site condition and vegetation control treatment for any group. Shrub cover was significantly greater on flat sites than either bedded or mounded sites in 2004 ($F_{2, 20} = 16.5$, $p < 0.001$), although by 2005 shrub cover on bedded sites was no longer significantly different than flat sites (Table 3.3.4). Additionally, the herbicide treatment significantly reduced shrub cover when compared to the chop treatment during both years ($F_{1, 20} = 67.2$, $p < 0.001$, and $F_{1, 20} = 41.8$, $p <0.001$, respectively). In 2004, there was significantly more graminoid cover on chopped sites than those treated with herbicides ($F_{1, 20} = 14.5$, $p = 0.001$), but no difference in 2005 ($F_{1, 20} = 0.1$, $p = 0.753$).

Regression analysis

In 2004, mortality was negatively related to percent soil moisture ($r^2 = 0.405$) (3.3.3A). No other single variable accounted for over 5 percent of the variability in seedling mortality after one year. In 2005, the relationship between seedling mortality and percent soil moisture was much weaker than in 2004, accounting for only 8 percent of the variability. The strongest predictors of mortality in 2005 were soil temperature at 15 cm ($r^2 = 0.295$) and soil surface temperature ($r^2 = 0.124$) (Figure 3.3.3). The predictive model for second year seedling mortality was best fitted with the following equation:

$$Y = -214.046 + 7.154 * X_1 + 3.015 * X_2 + 1.688 * X_3 \qquad (2)$$

$$r^2 = 0.451,\ n = 40,\ SSE = 4284.66,\ p < 0.001$$

where Y is mortality (%), X_1 is soil temperature at 15 cm (°C), X_2 is the square root transformation of percent graminoid cover, and X_3 is soil surface temperature (°C).

In 2004, the individual variable most strongly related to root collar diameter was percent soil moisture, with an inverse relationship that accounted for 7.5 percent of the variability. In 2005, the relationship between root collar diameter and percent moisture was much stronger, with an r^2 value of 0.334 (Figure 3.3.4). The next strongest relationship was a positive relationship with percent full sunlight, accounting for 26.2 percent of the variability. Abundance of surrounding vegetation was inversely related to

growth ($r^2 = 0.148$). In 2005, the model that best fit the data accounted for 58.5 percent of the variability:

$$Y = 21.819 - 0.139 * X_1 - 0.742 * X_2 + 1.203 * X_3 \qquad (3)$$

$r^2 = 0.585$, n = 40, SSE = 171.50, $p < 0.001$
where Y is root collar diameter (mm), X_1 is percent soil moisture at 6 cm, X_2 is the square root transformation of shrub percent cover, and X_3 is the square root transformation of fern percent cover.

3.3.4. Discussion

Microsite response to site preparation

We classified our site preparation treatments in two groups based on the primary treatment function; "planting site conditions" included mounding and bedding, which are used to alter soil conditions and alleviate limitations associated with flat planting, and "vegetation control treatments" included chopping and herbicide, which are primarily used to reduce competition for resources from surrounding vegetation. The function of each treatment inherently suggests the respective ability of the treatment to impact the response variables. For instance, bedding and mounding would be expected to have a stronger affect on soil moisture and temperature than either chopping or herbicide. For the most part, we found that microsite conditions responded as expected to the site preparation treatments applied.

Consistent with previous reports, we found that bedding and mounding treatments resulted in a reduction in soil moisture and an increase in soil temperatures. Bedding is commonly used to alleviate limitations from excess moisture by improving soil drainage and increasing aeration near the soil surface (Pritchett, 1979; McKee and Wilhite, 1986), and one of the main purposes of mounding is reducing excess soil moisture on a growing site (Sutton, 1993; Londo and Mroz, 2001). The greatest soil temperatures at 15 cm reported in this study occurred on mounded sites. Mounding is used in northern latitudes to raise soil temperatures by increasing site exposure, inverting and "capping" the insulating surface organic layer with mineral soil, and bringing the mounded soil above the ground level (McMinn, 1985; Sutton, 1993; Londo and Mroz, 2001). Although bedding is not used for this purpose in the southeastern United States, increased soil temperatures have been associated with bedding as well (Trettin et al., 1996). Vegetation control treatments did not have very strong effects on temperature within the soil, suggesting that the soil disturbance created by bedding and mounding is largely responsible for increased temperatures at 15 cm.

With exception to the untreated check, all treatment combinations included either chopping or herbicide for the control of surrounding vegetation. However, in both growing seasons the plots treated with only chopping (CF) did not significantly reduce vegetation cover when compared to the check. Chopping primarily crushes above-ground biomass, but does not control stump sprouts and often results in rapid regrowth of woody vegetation (Fredericksen et al., 1991). Previous studies have demonstrated limited success of chopping for reducing vegetation when compared to more intensive

mechanical treatments (Miller, 1980). Because we found no significant interactions between planting site conditions and vegetation control treatments, our results suggest that reductions in vegetation caused by CM and CB treatments can be attributed to effects of mounding and bedding, respectively, rather than the chopping treatment.

We found the treatment combinations that included mounding (HM and CM) had the lowest percent cover of surrounding vegetation after two growing seasons. At the local seedling level, where vegetation measurements were taken, mounding was perhaps the most intensive treatment used in the study. To create each individual mound, soil was scooped from the ground, inverted, and then deposited adjacent to the pit. Scooping the soil pulls vegetation from the ground and severs roots, and the inverted mineral soil on which each seedling was planted provides a barrier to returning vegetation (Sutton, 1993). Vegetation is effectively eliminated from the immediate vicinity of the planted seedling, but is often unaffected between mounds. It is unclear, however, how long the inhibitory effect of mounding on nearby vegetation will persist as the mounds shift and settle over time.

Herbicides provided additional vegetation control when used in combination with mounding or bedding and were clearly more effective at reducing surrounding vegetation than chopping. However, we found a greater increase in vegetation abundance from 2004 to 2005 in sites treated with herbicides (14% cover in 2004 to 44% cover in 2005) than sites treated with chopping (30% cover in 2004 to 51% cover in 2005), consistent with previous studies that show the effects of herbicides diminish significantly by the second year after application (Blake et al., 1987; Zutter and Zedaker, 1987). We found that the increase in total vegetation cover on herbicide sites from 2004 to 2005 was largely attributed to an increase in graminoids, which as a taxon typically respond well to site disturbance. The herbicide treatment used in our study, which was formulated to target woody vegetation, effectively controlled shrub cover through two growing seasons.

Reducing shrubs and preserving or increasing the herbaceous component of the understory is desirable for restoration and may provide the opportunity to increase biological diversity, a defining characteristic of properly managed longleaf pine ecosystems (Peet and Allard, 1993; Walker, 1993). Previous studies have demonstrated pronounced shifts in community structure following the use of site preparation (Schultz and Wilhite, 1974; Conde et al., 1983; Swindel et al., 1986). Understanding effects of site preparation on the structure and composition of understory vegetation is critical for ecological restoration (Noss, 1989; Glitzenstein, 1993; Hedman et al., 2000). Although we observed changes in percent cover of vegetation groups in response to our treatments, a detailed analysis of understory response is beyond the scope of this report.

Seedling response to microsite conditions

The strong inverse relationship between seedling mortality and soil moisture in 2004 suggests that greater soil moisture (within the range reported in this study) improves seedling survival during the first year after planting. Similarly, Larson (2002) found that dry conditions at the root system increased the likelihood of seedling mortality, and

Haywood (2007) associated drought conditions in the first growing season with reduced survival of planted longleaf pine seedlings. It is important to note that our study was conducted on poorly drained sites, where we would expect soil moisture levels to be relatively high. Despite significant reductions in soil moisture caused by mounding and bedding treatments, we previously reported [found] no significant treatment effects on survival at 8 months (Knapp et al., 2006). A high degree of within-treatment variability in seedling mortality may have masked some treatment effects; inconsistent depths to the hardpan affecting local drainage patterns likely resulted in drier conditions in some areas within plots. According to data from the National Climate Data Center (Hofmann Forest Station, 34°5' N, 77°2' W), precipitation during the study years was approximately normal when compared to the 30-year mean (2004 = 149.0 cm, 2005 = 153.9 cm, 30 year mean = 145.0 cm), suggesting that seedlings were not stressed by unusual conditions. Overall, we would expect that planting longleaf pine on sites with uniformly and/or excessively low moisture levels would result in higher mortality rates than we observed in this study (e.g. Rodriguez-Trejo et al., 2003).

With the exception of soil moisture, individual microsite factors were poor predictors of seedling survival or growth in 2004. The use of container-grown seedlings may have obscured other relationships because the growth medium surrounding the root system moderates local conditions, allowing seedlings to gradually adjust to the new growing environment after planting (Schultz, 1997; Barnett and McGilvray, 2000; Barnett, 2002). The plug of nutrient-rich medium creates favorable conditions for early root growth regardless of site conditions. Therefore, seedling response may not be representative of growing conditions during the very early stages of growth, resulting in weak relationships after the first growing season.

The predictive model for 2005 seedling mortality indicates that soil temperature and competition from graminoids were significant factors affecting seedling survival. In a study on artificial regeneration of longleaf pine in canopy gaps in Georgia and Florida, Rodriguez-Trejo et al. (2003) reported that extreme temperatures increased first year mortality by drying out and desiccating the root systems of longleaf pine seedlings during a severe drought. Our study was not conducted under droughty conditions, but our results also suggest that hot, dry conditions increase early mortality of planted longleaf pine seedlings. Additionally, Rodriguez-Trejo et al. (2003) found grass cover to be negatively related to seedling survival. Grasses typical of the longleaf pine ecosystem, primarily bunchgrasses and specifically wiregrass within the region of our study have shallow but dense and fibrous root systems that make them strong competitors for soil moisture and nutrients, especially when recently planted longleaf pines seedlings have not yet developed extensive root systems.

Although previous studies on resource availability have reported poor relationships between longleaf pine growth and soil moisture (Palik et al., 1997; McGuire et al., 2001), we found soil moisture to have the strongest relationship with root collar diameter in 2005. In contrast to the well drained sites of previous studies, the poorly drained growing conditions of our study appear to limit the seedling growth rate because of too much moisture. Similarly, studies on other southern pine species found that site preparations

used to increase drainage on poorly drained sites resulted in greater seedling growth rates (Pritchett, 1979; McKee and Wilhite, 1986). Shoulders (1976) reported that poor soil aeration reduced growth rates of slash pine seedlings by inhibiting root growth and the ability of existing roots to absorb water and nutrients. Therefore, the strong relationship between soil moisture and seedling growth is not surprising on poorly drained sites where excess moisture limits seedling growth potential. In addition, if weaker seedlings died on the drier microsites of our study, proportionally more of the healthier, strong-growing seedlings would remain to contribute to growth means at the plot level.

It is well known that longleaf pine is a shade-intolerant species (Boyer, 1990), and light may be a limiting factor for seedling growth under intact canopies. Gagnon et al. (2003) report significantly larger increments of diameter growth at the center of gaps (where light levels are highest) and decreasing growth rates toward the forest edge. Other studies on resource availability within forest gaps identify light as the most limiting factor for early longleaf pine growth (Palik et al., 1997; McGuire et al., 2001). In these studies and ours, seedling growth increased as light levels rose from 30 percent to around 70 percent full sunlight, above which additional sunlight did not appear to correspond with additional growth. In our study, sites had been clear-cut, sheared, and burned prior to treatment application. With no canopy to provide shade, first-year light levels exceeded 73 percent full sunlight on all treatments. By the end of the second year, however, understory vegetation had grown tall enough on some of the treatments (F, CF, HF, and CB) to bring light levels below 70 percent. As competing vegetation continues to grow around seedlings, we expect reduced light levels to further inhibit root collar growth of seedlings remaining in the grass stage.

We were not surprised to find that abundance of surrounding vegetation was inversely related to seedling growth. Based on field observation, the height and density of the shrub group made it the most likely to reduce light levels reaching the seedling, and our predictive model for 2005 root collar diameter included shrub cover as a significant variable. Previous reports suggest that shrub control is critical for longleaf pine establishment because seedlings cannot compete with fast growing woody vegetation (Croker and Boyer, 1975; Van Lear et al., 2005). In addition to reducing light levels reaching the seedling, surrounding vegetation competes for soil nutrients. Soil nutrients, especially available nitrogen, have been found to be significantly correlated to longleaf pine seedling growth (Palik et al., 1997; McGuire et al., 2001). In our study, we did not quantify nutrient availability and therefore cannot differentiate the competitive effects of surrounding vegetation as primarily above-ground or below-ground. However, it is clear that controlling competition, especially shrubs, is critical for increasing seedling growth.

An interesting result from our study was the positive relationship between fern abundance and root collar diameter in the 2005 predictive growth model. The dominant fern species throughout the study area was bracken fern (*Pteridium aquilinum* L. Kuhn), which is a common pioneer species in plantations following disturbances such as logging, burning, and site preparation. Herbicides, specifically those that target shrub species, aid establishment of bracken fern by reducing competition for resources (McDonald et al., 1999; McDonald et al., 2003). Our results suggest that similar site conditions (including

an absence of woody competitors) favor both longleaf pine seedlings and bracken fern through two years after site preparation. Bracken fern has also been reported to inhibit growth of surrounding vegetation, particularly herbaceous plants, through allelopathy (Stewart, 1975; Gliessman and Muller, 1978; McDonald et al., 2003). Consequently, the presence of bracken fern may provide additional competition control and result in increased availability of resources for longleaf pine seedlings, although herbaceous species richness and diversity could be adversely affected by the same allelopathic mechanisms.

3.3.5. Conclusion

Understanding the effects of resource availability on longleaf pine seedling survival and growth can help land managers choose appropriate site preparation treatments for regeneration efforts. Our study has shown that excess moisture on poorly drained sites is an important limiting factor for root collar growth. Site preparation treatments that improve drainage, as well as reduce competition for light and other resources, can be expected to maximize longleaf pine seedling growth. Therefore, mounding or bedding combined with herbicides are appropriate treatments for land managers wishing to rapidly establish planted longleaf pine seedlings on this site type.

However, if the management goal is to restore the longleaf ecosystem with its component species and processes, managers will need to consider broader effects of site preparation decisions. Site preparation techniques, particularly those that alter the micro-topography by changing soil conditions, may have lasting influence on other aspects of the ecosystem. For example, it is not clear how these treatments will affect the frequency or continuity of surface fires, which have traditionally maintained this ecosystem. Raised soil from mounding or bedding, along with decreased vegetation as a fuel source, may disrupt the spread of fire and result in future encroachment by woody vegetation. Our study also suggests short term changes in the structure of ground layer vegetation, which in turn may alter other ecosystem components or processes.

While our results indicate that appropriate site preparation can increase early growth of longleaf pine seedlings, it is not clear that advantages will persist throughout stand development. Previous studies on longleaf pine (Boyer, 1985; Boyer, 1996) and other southern pines (Haywood, 1980; Nilsson and Allen, 2003) suggest that short-term increases in seedling growth associated with site preparation may diminish with time. Therefore, understanding the long term effects of site preparation for longleaf pine restoration on poorly drained sites will require additional research throughout all stages of stand development.

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Table 3.3.1. Least square means of percent soil moisture at 6 cm, soil temperature (°C) at 15 cm, and soil surface temperature (°C) for each treatment combination in 2004 and 2005. Similar letters indicate no significant differences within a column ($\alpha = 0.05$); p-values are significance of treatment effect in ANOVA. Means are followed by standard deviation in parenthesis.

	Soil Moisture (%) at 6 cm				Soil Temp. (°C) at 15 cm				Soil Surface Temp. (°C)			
Treatment	2004		2005		2004		2005		2004		2005	
F	28.8^{b}	(5.4)	31.8^{a}	(4.7)	25.7^{f}	(1.3)	24.2^{d}	(1.3)	31.6^{a}	(3.2)	31.4^{e}	(2.0)
CF	28.1^{b}	(7.4)	30.1^{a}	(2.9)	26.3^{e}	(1.3)	24.8^{c}	(0.4)	32.8^{a}	(2.2)	31.8^{de}	(1.2)
HF	33.7^{a}	(7.3)	32.8^{a}	(4.7)	26.3^{e}	(1.3)	25.1^{bc}	(1.0)	32.3^{a}	(3.5)	31.6^{de}	(1.1)
CM	19.8^{c}	(9.8)	22.0^{b}	(5.7)	28.2^{a}	(1.9)	26.6^{a}	(1.2)	31.7^{a}	(4.0)	32.8^{bc}	(1.8)
HM	20.1^{c}	(8.0)	16.7^{c}	(2.3)	28.0^{ab}	(1.4)	26.4^{a}	(0.7)	32.2^{a}	(4.1)	32.2^{cde}	(1.9)
CB	18.8^{c}	(6.8)	18.4^{bc}	(4.0)	27.7^{bc}	(0.8)	26.2^{a}	(0.9)	32.9^{a}	(2.7)	32.3^{bcd}	(1.8)
HB	21.9^{c}	(7.6)	21.2^{bc}	(5.2)	27.2^{cd}	(1.9)	25.4^{b}	(0.6)	32.2^{a}	(2.4)	33.0^{b}	(2.7)
CHB	21.1^{c}	(7.7)	20.6^{bc}	(9.6)	27.0^{d}	(0.7)	25.4^{bc}	(0.6)	30.9^{a}	(2.2)	34.2^{a}	(1.4)
p-value	**< 0.001**		**< 0.001**		**< 0.001**		**< 0.001**		**0.154**		**0.011**	

Table 3.3.2. Least square means of percent soil moisture at 6 cm, soil temperature (°C) at 15 cm, and soil surface temperature (°C) from 2004 and 2005 factorial analysis. Similar letters indicate no significant difference within a treatment type and column ($\alpha = 0.05$); p-values are significance of treatment effect in ANOVA.

	Soil Moisture at 6 cm (%)		Soil Temp. at 15 cm (°C)		Soil Surface Temp. (°C)	
Treatment	2004	2005	2004	2005	2004	2005
Flat	32.0^{a}	31.5^{a}	26.3^{b}	25.0^{c}	32.5^{a}	31.7^{a}
Mound	20.9^{b}	19.3^{b}	28.0^{a}	26.5^{a}	32.0^{a}	32.5^{a}
Bed	21.2^{b}	19.8^{b}	27.4^{a}	25.8^{b}	32.6^{a}	32.7^{a}
p-value	**< 0.001**	**< 0.001**	**0.001**	**< 0.001**	**0.424**	**0.168**
Chop	23.4^{b}	23.5^{a}	27.3^{a}	25.9^{a}	32.5^{a}	32.3^{a}
Herbicide	26.0^{a}	23.5^{a}	27.1^{a}	25.7^{a}	32.2^{a}	32.3^{a}
p-value	**0.043**	**0.997**	**0.505**	**0.298**	**0.607**	**0.956**

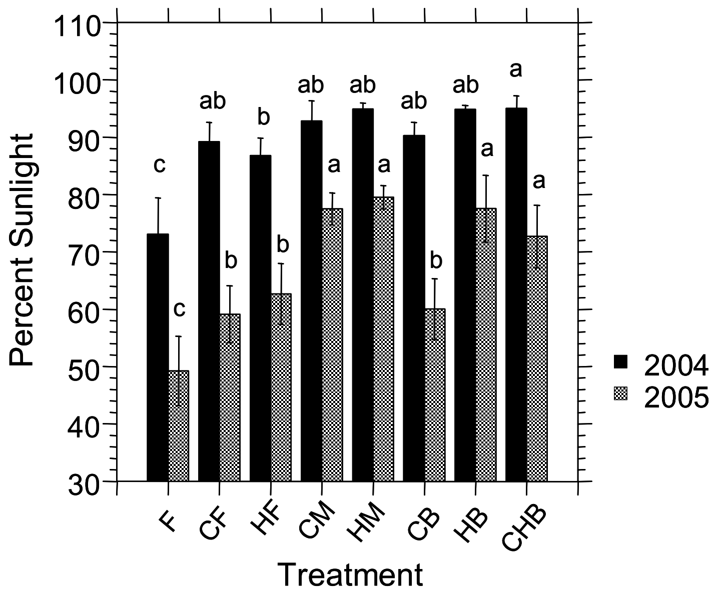
Table 3.3.3. Least square means of percent sunlight at the seedling level and total percent cover of surrounding vegetation from 2004 and 2005 factorial analysis. Similar letters indicate no significant difference within a treatment type and column (α = 0.05); p-values are significance of treatment effect in ANOVA.

	Percent Full Sunlight		Vegetation Cover (%)	
Treatment	2004	2005	2004	2005
Flat	88.0^{b}	60.9^{b}	41.3^{a}	61.6^{a}
Mound	93.8^{a}	78.5^{a}	9.9^{b}	30.4^{c}
Bed	92.5^{ab}	68.8^{ab}	15.2^{b}	51.0^{b}
p-value	**0.024**	**0.001**	**<0.001**	**<0.001**
Chop	90.7^{a}	65.6^{b}	30.3^{a}	51.1^{a}
Herbicide	92.2^{a}	73.2^{a}	14.0^{b}	44.2^{b}
p-value	**0.762**	**0.027**	**<0.001**	**0.036**

Table 3.3.4. Least square means of percent cover for ferns, forbs, shrubs, and graminoids from 2004 and 2005 factorial analysis. Similar letters indicate no significant difference within a treatment type and column (α = 0.05); p-values are significance of treatment effect in ANOVA.

	Ferns		Forbs		Shrubs		Graminoids	
Treatment	2004	2005	2004	2005	2004	2005	2004	2005
Flat	3.1^{a}	2.8^{a}	3.4^{a}	6.7^{a}	11.7^{a}	18.1^{a}	15.4^{a}	37.7^{a}
Mound	2.4^{a}	4.9^{a}	0.8^{b}	5.2^{a}	2.8^{b}	8.8^{b}	2.1^{b}	11.4^{b}
Bed	3.0^{a}	5.3^{a}	1.6^{ab}	6.8^{a}	5.2^{b}	15.6^{ab}	2.9^{b}	24.7^{ab}
p-value	**0.991**	**0.223**	**0.011**	**0.104**	**<0.001**	**0.038**	**<0.001**	**0.001**
Chop	2.5^{a}	2.6^{b}	2.9^{a}	6.4^{a}	9.9^{a}	19.8^{a}	9.3^{a}	24.3^{a}
Herbicide	3.1^{a}	6.1^{a}	1.0^{b}	6.1^{b}	3.2^{b}	8.5^{b}	4.3^{b}	24.9^{a}
p-value	**0.599**	**0.018**	**0.002**	**0.045**	**<0.001**	**<0.001**	**0.001**	**0.753**

A



B

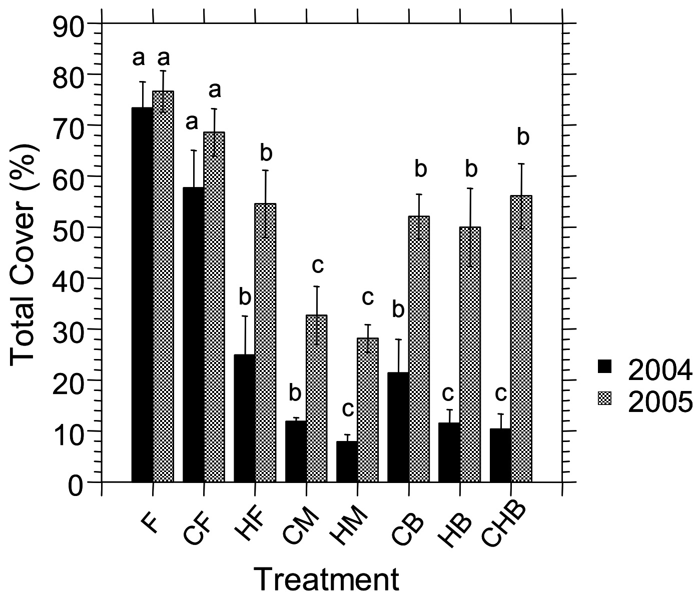
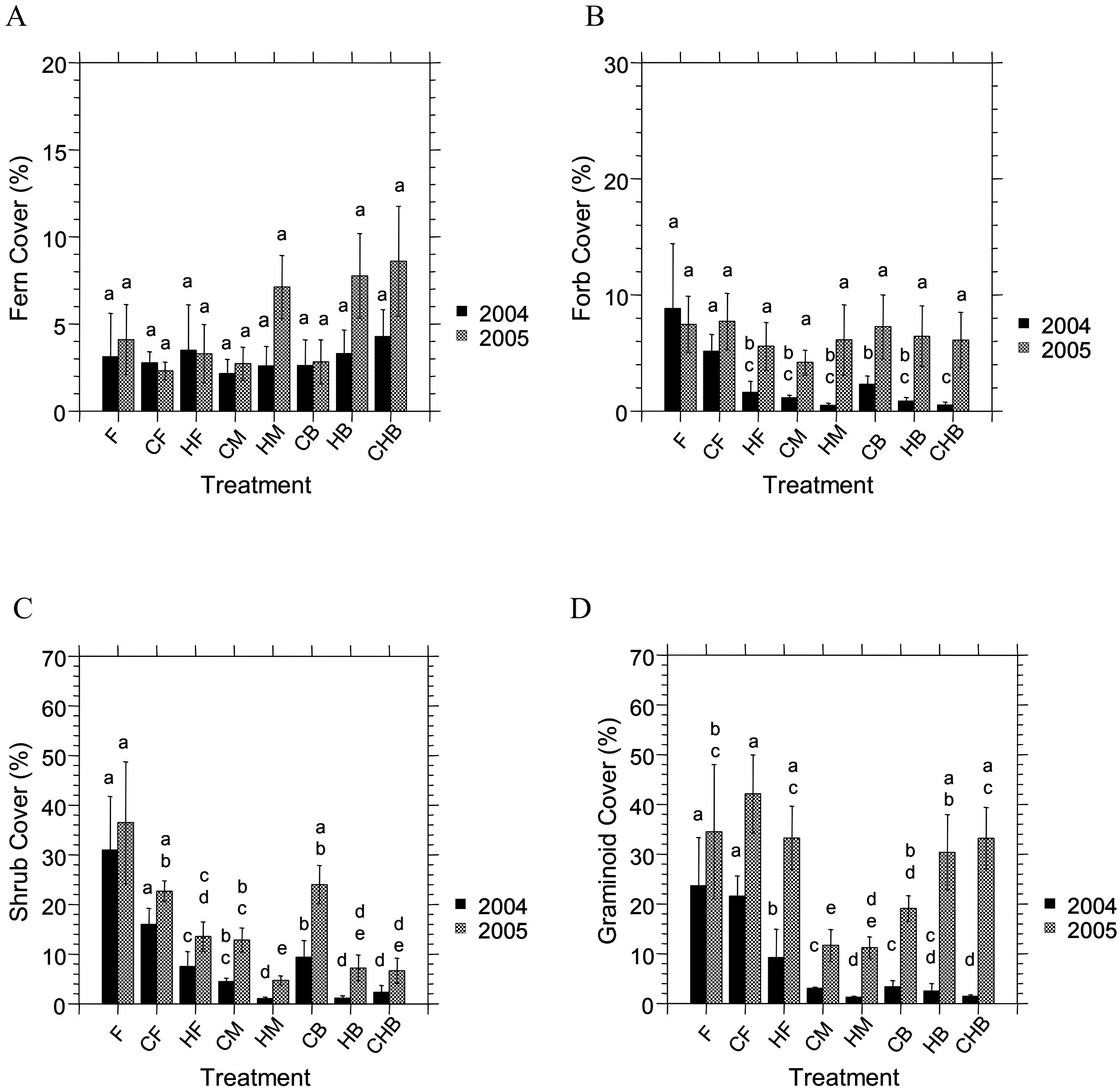
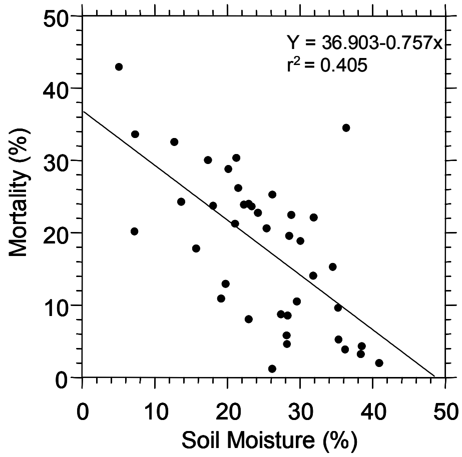


Figure 3.1.1. Least square means of A) percent sunlight at the seedling level and B) total percent cover of surrounding vegetation for each treatment combination in 2004 and 2005. Similar letters indicate no significant differences within each year (α = 0.05).

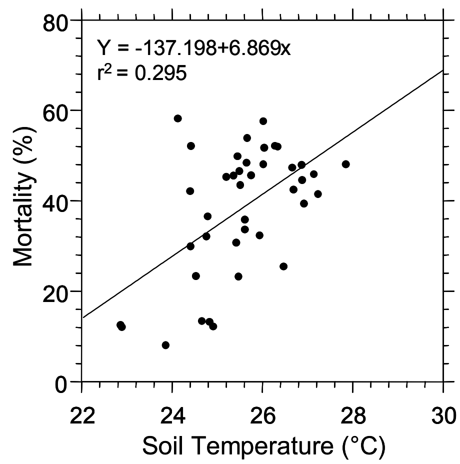


3.2. 2. Least square means of percent cover of A) ferns, B) forbs, C) shrubs, and D) graminoids for each treatment combination in 2004 and 2005. Similar letters indicate no significant differences within each year ($\alpha = 0.05$).

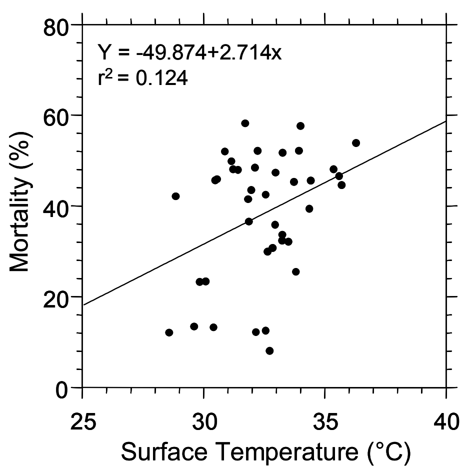
A



B



C



3.3.3. Scatterplots with regression lines and r^2 values for A) 2004 percent mortality vs. percent soil moisture at 6 cm, B) 2005 percent mortality vs. soil temperature (°C) at 15 cm, and C) 2005 percent mortality vs. soil surface temperature (°C).

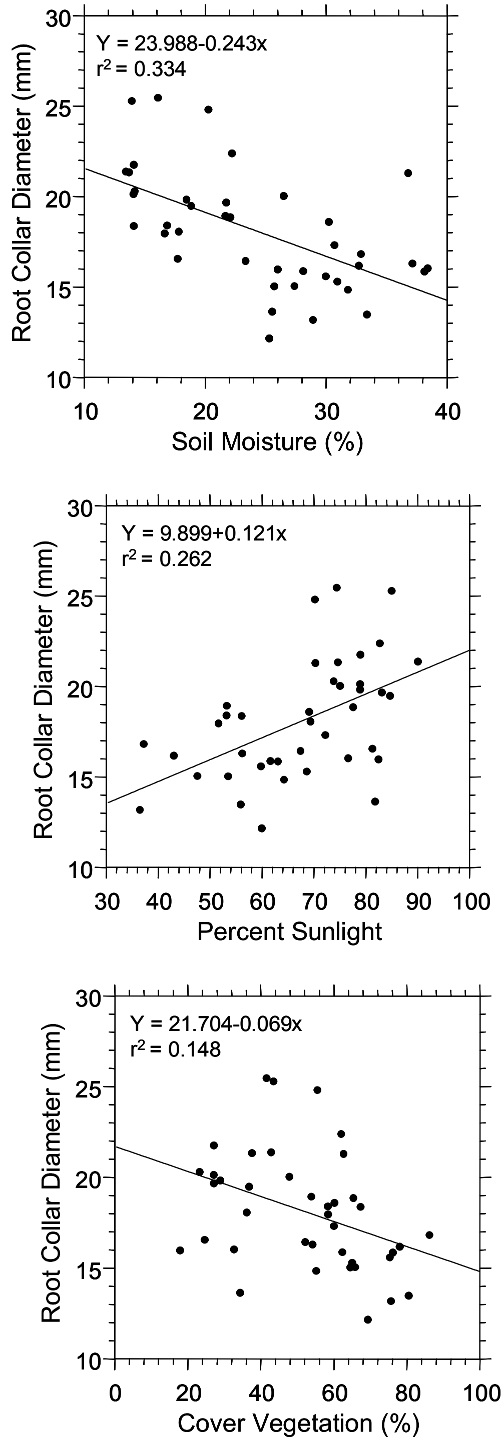


Figure 3.3.4. Scatterplots with regression lines and r^2 values for A) 2005 root collar diameter (mm) vs. percent soil moisture at 6 cm, B) 2005 root collar diameter (mm) vs. percent sunlight, and C) 2005 root collar diameter (mm) vs. percent cover of surrounding vegetation.

3.4. Ground layer vegetation responses to moderate site preparation methods on North Carolina flatwoods sites

3.4.1. Introduction

Longleaf pine exhibits broad ecological amplitude, naturally occupying sites that are typically nutrient limited, but range from excessively well-drained sandhill conditions through mesic well-drained sites, to somewhat poorly drained flatwoods sites where it may dominate or share dominance with pond or slash pine, depending on the geographic location (Peet 2006). Because the plant and animal communities associated with LLP vary with site conditions and geography, effective conservation of the diversity within this ecosystem will require restoration across the range of geography and site conditions (Walker and Silletti 2006). While the ground layer varies markedly across these gradients, regenerating longleaf pine must be a common objective, and factors that affect the establishment and growth of this species are well understood (Brockway et al. 2006, Johnson and Gjerstad 2006). Previous research has shown that keys to successful longleaf pine establishment and rapid early growth include planting vigorous container-grown seedlings and control of potentially competitive vegetation. The latter may be achieved prior to planting through effective site preparation, or post-planting with continued vegetation management. Post-planting vegetation control, except by prescribed burning, is not generally needed if sites are well prepared prior to planting.

Methods of site preparation for longleaf pine have been studied for establishment on upland sites; however, the benefits of site preparation for planting longleaf pine on wetter sites have received little attention. Knapp et al. (2006) reports on the effects of site preparation on the survival and early growth of longleaf seedlings planted on poorly drained flatwoods sites. Methods tested included combinations of mechanical treatments that altered the planting site condition (bedding or mounding) combined with a chop and/or pre-plant broadcast herbicide (imazapyr + triclopyr) application to reduce competition. Treatments represented a range of approaches commonly used for regenerating slash and loblolly pines on previously forested flatwoods sites (Johnson and Gjerstad 2006). While neither mechanical nor chemical treatments changed the 20-month seedling survival rate, treatments increased early growth. Bedded or mounded plots had larger seedlings (root collar diameter) than flat-planted plots, and a pre-plant herbicide application improved growth; effects of chemical and mechanical treatments were additive, with plots receiving both bedding and herbicide having the largest seedlings. These results are similar to those reported for planted slash (Pritchett 1979, Pienaar et al. 1983, Burger and Pritchett 1988, Shiver et al. 1990, 1991; Kline et al. 1994) and loblolly pines (McKee and Wilhite 1986), indicating that methods applied on poorly drained flatwoods sites for slash and loblolly also benefit longleaf pine seedlings.

In spite of benefits to planted pines, there remains some concern about possible negative effects on the composition and structure in the associated ground layer vegetation, especially in sites that support a “natural” ground layer community at the time of pine regeneration (Brockway et al. 2006, Johnson and Gjerstadt 2006). A majority of flatwoods site preparation studies have used bedding. In addition to altering the planting

site conditions for pine seedlings (Pritchett 1979, Outcalt 1984, Haywood 1987, Morris and Lowery 1988), bedding generally reduces woody competitors, with concomitant increases in herbaceous cover and species richness (Lauer and Zutter 2001, Knapp et al. 2006). Mounding, a mechanical treatment not used extensively in the management of southern pines, may produce similar benefits as bedding (Sutton 1993, Londo and Mroz 2001), but unlike bedding which disturbs the soil in long continuous rows, mounding produces discontinuous disruptions disturbing a smaller proportion of the site and the existing ground cover vegetation.

Bedding is often combined with chemical vegetation controls, with the exact herbicide recommendations based on the type of competing vegetation to be controlled (Johnson and Gjerstadt 2006). Because woody vegetation competition is regarded as more detrimental to longleaf pine seedling early growth than herbaceous competition, chemical formulations for site preparation on flatwoods sites typically target this group, and by many accounts effectively reduce woody species (Lauer and Glover 1998, 1999; Zutter and Miller 1998; Vander Schaaf and South 2004; Zhao et al. 2008). Effects on other vegetation components, e.g. grasses and forbs, vary. Herbicides have been reported to produce an initial, short-term (2-3 years post-treatment) reduction in herbaceous species richness (Blake et al. 1987), an increase in richness (Miller et al. 1995), or no change (Miller and Chamberlain 2008). Herbaceous abundance may also decline in the short term, subsequently increasing in the absence of shrub competition (Miller et al. 1995, Harrington et al. 1998, Haywood 2005). Within the ground layer vegetation, individual species or groups of species have been shown to respond differently to the same treatment (Litt et al. 2001, Harrington et al. 1998, Jose et al. 2008, Miller and Chamberlain 2008, Freeman and Jose 2009). In one study, a single pre-plant application of imazapyr and triclopyr to control evergreen shrubs during site preparation resulted in increases in forbs, legumes, and bluestem grasses, and reductions in woody vines and shrubs (Miller and Chamberlain 2008). Harrington et al. (1998) reported similar findings with herbicide-related increases in grasses, forbs, and shrubs, but decreases in woody vines and hardwoods. Both of these studies included prescribed fire as part of the site preparation. Short-term effects of chemical applications are somewhat variable because they depend on many factors including the specific chemical applied, application rates and timing, vegetation composition, and concurrent management treatments (Litt et al. 2001).

While immediate effects on associated vegetation have been shown to vary following site preparation, it is clear that herbaceous cover and diversity change during plantation development, especially in response to site preparation, and gradually as pines gain dominance (Miller et al. 2003). The introduction of prescribed fire early in the development of longleaf pine stands, typically at age 2-3 years, further complicates patterns in ground layer vegetation performance. A better understanding of patterns of change will provide insights into vegetation processes that may be helpful in ecosystem restoration.

The overall objective of this study was to determine the short-term effects of site preparation treatments on the composition and structure of non-pine vegetation in

longleaf pine plantations on poorly drained flatwoods sites. We addressed several specific questions: (1) Does vegetation control method affect total vegetation cover or species richness? (2) Does vegetation control method affect abundance or richness of selected plant groups or individual species? (3) Does planting site manipulation (by bedding or mounding) affect total ground layer cover and species richness? (4) Does planting site manipulation (by bedding or mounding) affect abundance or richness of selected plant groups or individual species?

3.4.2. Methods

Refer to Section 3.1 for descriptions of study site, treatments, and experimental design

Data collection

We sampled ground layer (< 1 m tall) vegetation in 2004, 2005, and 2006, during the first three growing seasons after planting. In each treatment unit, we established 4 transects with starting points evenly spaced along the long axis and running parallel to the short axis of the measurement core area. We randomly located 3 sample quadrats (1m x 1m) along each transect for a total of 12 square-meter quadrats per experimental unit. In each sample quadrat we estimated vegetation cover by species and recorded cover as one of the following percent cover classes: trace-5%, 6-25%, 26-50%, 51-75%, and 76-100%. One set of 4 nested measurement plots (hereafter nested plots) measuring 0.31 x 0.31 m (0.1 m^2), 1 x 1 m (1 m^2), 3.1 x 3.1 m (10 m^2), and 10 x 10 m (100 m^2), was established in each treatment unit, with the 1 x 1 m scale superimposed over the last quadrat in a randomly selected transect. Beginning at the smallest scale, we recorded all species present in each of the nested plots and then surveyed the entire experimental unit for additional species. We sampled the same quadrats and nested plots in all three years.

Calculations and statistical analysis

We assigned ground layer species to one of six functional/growth-form groups: large graminoids (grasses with leaves >15 cm long, forming dense bunches or looser clumps), small graminoids (smaller grasses, sedges, and rushes, varying in habit including small cushion-forms or rosettes, tufts, small bunches), forbs (non-graminoid herbs of various forms and sizes including basal rosettes with scapose inflorescences and clumps of vertical stems with cauline leaves, ranging in height from <3 cm to > 100 cm), ferns (both tussock forming and rhizomatous), vines and trailing species, and woody species (shrubs and tree seedlings). Assignments of taxa to functional groups are shown in Appendix GL1. We also analyzed cover and richness by two general habits: herbaceous or woody. The herbaceous group included the small and large graminoids, forbs, and ferns, and the woody species included the woody functional group. Woody vines capable of secondary growth were assigned to the woody group and herbaceous trailing species to the herbaceous group. We followed Kartesz (1999) as our taxonomic standard.

For analysis of abundance we first converted cover classes to the mid-point of each class. For total cover in a quadrat we summed the percent cover of individual species; where

species overlapped within a quadrat, the total cover exceeded 100%. We calculated the mean quadrat total cover per treatment plot (n=12) and used this value for analysis. For the analysis of functional group abundance, we totaled cover by functional group in each quadrat and averaged abundance per experimental plot. We also tallied species richness per sample quadrat (1 m^2) and calculated a mean richness (n=12) per treatment unit.

Using nested plot data, we tallied species richness (the number of species present) at each spatial scale for each plot. We also counted species present in each functional group.

We tested for treatment effects on the following abundance and richness variables: total cover, cover by woody and herbaceous groups, cover by functional group, total plot richness, richness by woody and herbaceous groups, richness by functional group, abundance of selected common species, and richness at various sampling scales. We used mixed model analysis of variance with random block and block*trt effects and an autoregressive covariance structure (Littell et al. 1996, SAS 2003). Using contrast statements in selected analyses, we tested the effect of using an herbicide as part of the experimental treatment to control vegetation (mean of HB, HF, HM, and CHB compared to the mean of CB, CF, CM, and F). Finally, we tested for effects of planting site modifications (mechanical treatments: flat, bedded, or mounded) on selected response variables (total cover, total richness, woody cover and richness, herbaceous cover and richness). We did this in two ways. First, we tested for a difference between the mean of HB, HM, CB, and CM plots and the mean of HF and CF plots. This 'mechanical contrast approach' did not allow us to test for differences among the three planting site conditions (B, M, and F). To evaluate the possible differences, in a separate analysis, we excluded the F and the CHB treatments and analyzed the remaining treatments (CF, HF, CB, HB, CM, HM) using a 2 x 3 factorial design with two competition control methods (herbicide and chopping) and three planting site conditions. Using this 'factorial approach', the effects of using herbicides compared to chopping (no herbicides) were identical to the results in previous analyses using all the data. There were no differences between bedding and mounding, and results were similar to the contrast analysis. For simplicity we present results from the mechanical contrast analysis.

We performed initial analyses of total cover and richness (mean of species richness in the 12 1-m^2 sample quadrats/plot) using a mixed model with repeated measures. Because the initial analysis showed significant trt, year, and trt*year interaction effects, we examined treatment effects within years in separate analyses in order to better compare immediate effects and persistent effects at different points in time.

Our sampling was not designed to capture changes in rare species, so we tested for treatment effects only on the most commonly occurring ground layer species. We ranked individual species by the frequency of occurrence in all 1m x 1m quadrats (n=480) in 2006 and tested for treatment and herbicide effects on the cover and frequency of the 20 most common species. (Individual species abundances in all treatment plots are summarized in appended data file.)

In a final group of analyses of the nested plot species presence data, we tested for treatment and year effects on total species richness, species richness of forbs (the herbaceous group contributing the most species), and species richness of shrubs (the woody group contributing the most species) at different spatial scales.

Unless specified, we accepted an alpha level of 0.05 for all statistical tests and used Tukey-adjusted p-values (Proc Mixed; SAS Statistical Software; SAS Institute 2003) when testing for differences between least square means.Variables were transformed as needed to meet requirements for parametric analyses.

3.4.3. Results

Total vegetation cover and species richness

For all treatments, ground cover was lowest the first season after planting trees (2004), ranging from 19.9% in the CHB treatment to 73.1% in the flat-planted check (F) (Figure 3.4.1) and increased markedly the following year (2005 range: 62.0% in HF to 108.9% in CF plots). Mean cover decreased from 2005 to 2006, following a prescribed management burn, in the CB, CF, and F plots, but increased in all the others.

There was a significant treatment effect on total cover in all years (Table 3.4.1), but the differences among treatments decreased with time. In 2004, all treatments had less total ground layer cover than the untreated check (F), but by 2006 the F plots differed only from the HM and HB treatments (Figure 3.4.2). During the first two years the highest total cover was measured in the F, CF, and CB plots, while treatments that included herbicides along with the CM treatment had less. In 2005, for example, the HB, HF, and HM treatments had the least cover (63.5%, 62.0%, and 63.1%, respectively), but they were not different from the intermediate CHB and CM treatments. The difference between treatments with herbicides and those without was significant for all years (Table 3.1.1; Figure 3.4.2 insets). This difference decreased through time, but remained significant. Plots with beds or mounds had significantly less total cover than flat planted plots in 2004 and 2005, but the difference was not significant at the end of the 2006 growing season (Table 3.4.1). The overall pattern through time is one of decreasing effect of planting site modifications (mechanical treatments), while the herbicide effect persisted.

Total species richness increased in all treatments through time (Figure 3.4.3). Richness in treatments with the lowest ground cover in 2004 tended to increase more than in treatments with higher initial cover (Figure 3.4.3). In 2004 the number of species per m^2 ranged from fewer than 6 (5.5) to 11.8, but by 2006 the range had shrunk to 9.6 – 12.9 (Figure 3.4.4). An examination of the within year treatment effects are consistent in that there was a treatment effect in 2004 and 2005, but none at the end of the 2006 growing season (Table 3.4.1).

During the first measurement season, richness in CB, CF, and F plots was higher than that in CHB, HB, HF, and HM (Figure 3.4.4). CHB plots had the lowest richness, but it

was not different from other treatments that included herbicide. In 2005 CF plots had the highest richness, which was significantly different from HB, HF, and HM treatments; richness in other treatments was intermediate with few significant differences. Richness in the untreated check (F) and the most intensely treated CHB plots were not different from each other, or from any other treatments. By 2006, there was no significant treatment effect on species richness. In all years herbicide treatments had significantly lower species richness (species/m^2) than treatments with no herbicides (Table 3.4.1, Figure 3.4.4 insets). Although total species richness was always greater in flat planted plots compared to plots with raised planting sites (bedded or mounded), the difference was significant only in 2004 (Table 3.4.1).

Woody versus herbaceous species cover and richness

There were significant treatment effects on woody species cover and richness in all years (Table 3.4.2; Figures 3.4.5-7). The patterns were similar to results in total cover and richness, with a notable exception: woody plant richness in CM was not different from other non-herbicide treatments. In 2004, woody cover in the F treatment was highest and significantly greater than in all treatments with herbicides and the CM plots. This pattern persisted in 2005, but by 2006 the F plots had greater woody cover than only the CHB, HB, and HM treatments. The significant effect of including herbicide in the site preparation (Table 3.4.2) is shown in Figures 3.4.5-7 (insets). Regarding mechanical treatment, woody cover was significantly greater in flat plots than in plots with bedding or mounding for the first 2 years. The effect of herbicides on woody species richness was highly significant ($p<.0001$ in all years), with herbicide treatments having fewer species/m^2 in all years, though the effects were reduced through time. Neither woody nor herbaceous species richness was changed by mechanical treatments.

Although analyses showed no treatment effect on herbaceous cover or richness in 2004, the herbicide contrasts indicated that herbicide treatments had both less cover ($p=0.0219$) and lower richness ($p=0.0111$) than non-herbicide treatments. Both treatment and herbicide effects on herbaceous cover were significant in 2006 (Figure 3.4.7). Herbaceous cover in the CHB treatment was higher than in the F and CB plots with other treatments intermediate and not different from each other or the extremes. The coincidence of treatment and herbicide effects through time suggest the importance of the chemical treatment in driving the overall treatment effects.

Cover and species richness of functional groups

In all years, the woody species group was the most abundant functional group in the plots, ranging from about 15.5 to 53.3% in 2005 when the group cover was highest (Figures 3.4.8-10). The maximum mean cover for any of the other groups was large graminoid cover in the CF treatment, which reached 19.4% in 2005. In 2005 small graminoids peaked at 17.1% in CHB plots and vines at 14.8% in CF plots. In 2006, forbs and ferns reached cover maxima of 11-13% in several treatments and 12.0% in CHB, respectively.

Treatment effects on functional groups' cover varied by year and group (Tables 3.4.3-5, Figures 3.4.8-10). Early treatment effects (2004) were significant on large graminoids, forbs, vines, and woody species; cover was highest in either the flat-planted check (F) or CF treatments for each of these groups. In each case the highest cover treatment was greater than in the CHB, the lowest. Based on linear contrasts of herbicide compared to no-herbicide treatments, cover in herbicide treatments was significantly lower in all of these groups. At the end of the 2005 growing season, treatment effects were significant for all groups except forbs, but effects differed among groups. Treatment effects on large graminoids, woody species and vines were similar to each other and to results in 2004. The highest cover for these groups was recorded in the F, CF, and CB treatments and the lowest cover was measured in treatments with herbicide (CHB, HB, HF, and HM) and CM. The highest mean covers for these groups were significantly greater than the lowest (Figure 3.4.9). The herbicide contrast was significant for each group and confirmed this general pattern. The treatment effects in small graminoids and ferns were similar to each other, with an overall positive herbicide effect. Highest small graminoid and fern cover were found in the CHB and HM treatments, both of which were significantly greater than the lowest cover in F. By 2006, an overall treatment effect was detectable only in the cover of woody species and ferns; however, herbicide treatments showed positive effects on small graminoids and ferns, and negative effects on woody shrubs (Figure 3.4.10).

Treatment effects on richness within functional groups changed through time (Figures 3.4.11-13). Woody species was the only functional group with a significant treatment effect in all sample years, and in all years the herbicide contrast showed fewer woody species per square meter than non-herbicide treatments. Only forbs showed no significant treatment effect in any sampling period. For large graminoids, treatment effects were shown in the first two years post-treatment but absent in the final year of the study. Small graminoids showed a delayed and transient treatment effect evident in 2005 but gone by 2006. There was a treatment effect on the richness of vines in the first and third seasons, while a treatment effect on fern richness was shown only in 2006, three seasons post-treatment and following a prescribed fire in the study plots.

Abundance of common species

We tested for treatment effects on both the 2006 mean percent cover and 2006 mean relative frequency of the 20 most common woody and herbaceous species (Table 3.4.6), which included 9 woody and 11 herbaceous taxa. Of these 20, significant treatment effects were found on 9 of them, including 6 woody and 3 herbaceous taxa. Significant herbicide effects were measured on all but the following 8 common taxa: *Lachnanthes caroliniana, Lyonia mariana, Rhexia petiolata*, *Rhynchospora* spp., *Schizachyrium scoparium, Smilax laurifolia*, *Vaccinium crassifolium*, and *Xyris* spp. Of the taxa with significant herbicide effects, 5 taxa, all herbaceous, appeared to increase with herbicide treatments: *Andropogon capillipes*, *Dichanthelium* spp., *Eupatorium* spp. *Polygala lutea*, and *Pteridium aquilinum* (Table 3.4.7). Of this group, *Pteridium* stands out as a species that increases rhizomatously and forms clones. Results for two measures of abundance, cover and relative frequency, were similar (Table 3.4.7).

Figures 3.4.15 and 17 show the specific treatment differences for the 6 woody species with both treatment and herbicide effects. *Ilex glabra* (inkberry) and *Persea borbonia* (red bay) are evergreen with somewhat waxy green leaves and the potential to grow taller than 3 m. Of the deciduous taxa, *Aronia arbutifolia* (red chokeberry) and *Gaylussacia frondosa* (dangleberry) may grow as tall as 2 m, but *G. dumosa* (dwarf huckleberry) and *Vaccinium tenellum* (dwarf blueberry) are low shrubs (< 5 dm). All of these can re-sprout if the top is removed, which commonly occurs with burning or mechanical disturbance. Except for *Persea*, all increase via rhizomes forming large patches. *Persea* alone can assume a tree form. Although there was a treatment effect, least square mean comparisons indicated that in most cases only the treatments with highest abundance differed significantly from the lowest cover or frequency treatments. The highest cover of these common woody species generally occurred in the F or CF treatment, though there was some variation (Figure 3.4.17). Other sometimes high abundance treatments included CB and CM. Lowest woody species cover was usually found in the CHB, HB, HF, and HM plots. *Vaccinium tenellum* appeared to respond negatively to treatments that raised the planting surface (bedding and mounding) and the presence of herbicides.

Three herbaceous taxa showed both treatment and herbicide effects, *Andropogon capillipes* (chalky bluestem), *Aristida stricta* (wiregrass), and *Eupatorium* spp. (Figures 3.4.16, 3.4.18). The two large grasses responded in nearly opposite ways to treatments. The bluestem relative frequency was highest in CHB, HB, HF, and HM treatments (not different from each other) and significantly lower in CB and CM treatments. Frequencies in F and CF were intermediate, but still lower than the highest treatment, CHB. Wiregrass frequency was highest in CF plots, which was significantly greater than in all herbicide treatments and CM. Results were similar when cover was analyzed. *Eupatorium* spp. included a mix of species, some being characteristic of undisturbed high quality natural areas (e.g., *E. rotundifolium*, *E. leucolepis*) while one of the most abundant, dog fennel (*E. capillifolium*) is found in highly disturbed areas. All of the species tend to increase with mechanical disturbance, which produces sites suitable for seedling establishment. This is consistent with the lowest abundance in flat planted treatments (F, CF, and HF; Figure 3.4.18) and greatest abundance in CHB, HM, HB, and CB plots. Of these three, *Andropogon capillipes* was the one that increased following exposure to the herbicides used in this experiment (Table 3.4.7).

Species richness in nested plots

Mean species richness increased at all scales through time (Figure 3.4.19). Richness averaged across all treatments increased from about 3.0 to 5.8 species/0.1 m^2 and from 23.3 to 30.2 species/100 m^2 during the study. The repeated measures analysis of variance showed significant treatment and year effects on total species richness at all sampling scales, but no interaction (0.1, 1, 10, 100 m^2; Table 3.4.8; Figure 3.4.20). Treatment differences decreased with increased sampling scale: at 0.1 m^2 the lowest diversity plots (HB and HM) had 53% of the highest (CF), and at 100 m^2 the lowest HM plots had 77% of the highest CB mean (Figure 3.4.20). Both herbicide and mechanical treatment effects were significant at the smallest scale (non-herbicide > herbicide; flat>bedded or mounded treatments). The mechanical effect difference approached significance (p=0.077) at the 1

m^2 scale and the herbicide effect was highly significant for richness in 100 m^2 samples (Table 3.4.8; Figure 3.4.20 insets).

Because previous analyses showed that the woody species response to treatments differed from herbaceous species, we tested for treatment and year effects on the woody and forb functional groups at various spatial scales. Forbs were of interest because they contributed the greatest number of species to the herbaceous group. There were no treatment effects on the forb group at any scale (Figure 3.4.21), but forb richness increased from 2004 to 2006 (year effect) at all sample scales (Table 3.4.9; Figure 3.4.22). Except at the smallest scale, richness in 2005 was intermediate and not different from other years. In contrast, for the woody group we found significant treatment effects at every scale but no year effect at any scale (Table 3.4.10, Figure 3.4.23). Treatment differences, most pronounced at small scales, were damped with increasing sample area. Herbicide treatments generally showed the lowest woody diversity, while higher woody species richness occurred in chopped plots. Combining chopping with herbicide appeared to ameliorate the chemical effect on richness; richness in the CHB treatment was not different from any other treatment at scales $\geq 1m^2$.

3.4.4. Discussion

In an overview of results, two main patterns emerge: (1) the effects of chemical application persisted through the study but effects of bedding or mounding diminished, and (2) the patterns of treatment effects on total vegetation abundance and to a lesser degree species richness tracked treatment effects on the woody component or the shrub functional group. Both of these observations can be related to the facts that shrubs were the most abundant vegetation group on the sites and that the herbicide treatment formulated to control the shrubs was very effective. Overall, our results were consistent with previous studies on flatwoods sites, including the finding that three years after site preparation there was no significant treatment effect on species richness and, except for two treatments (HB and HM), vegetation cover was not different from the flat planted check.

Mechanical treatment effects on abundance

Flatwoods are typically poorly drained and dominated by some form of shrubby vegetation, even sites that are burned relatively frequently (Peet 2006). In such sites, bedding has been widely used and is even considered essential for pine regeneration (Lauer & Zutter 2001, Zhao et al. 2008). Associated benefits include better drainage, concentrated soil nutrients, and reduction in competing vegetation, especially shrubs (Schultz 1976; Conde et al. 1983a, b; Lauer & Zutter 2001). Mounding is comparatively rarely used in the southeast, but is used to provide similar benefits to planted pines in more northerly sites (Sutton 1993, Londo & Mroz 2001). As expected, we found that these treatments did reduce woody species cover but only modestly (46% in flat to 35% in bedded/mounded treatments), and by the third year the effect was not significant. An immediate reduction followed by rapid recovery is commonly reported (Conde et al. 1983, Swindel & Smith 1986, Lauer & Zutter 2001). Unlike previous studies, we found

no plot level change in herbaceous cover that could be attributed to bedding/mounding, though we note an immediate reduction in large graminoid cover (p=.099), which persisted near significance in 2006 (p=0.0512). Conde et al. (1983a) reported an overall increase in the abundance of grasses with bedding, but the increasers were predominantly small *Dichanthelium* species and chalky bluestem (*Andropogon capillipes*), while wiregrass (*Aristida stricta*), an ecologically conservative species declined (See also Hebb 1971, Moore 1974, Schultz 1976). Others have reported a general increase in herbaceous cover or biomass in the first 2-3 years after bedding (Schultz 1976, Moore & Terry 1980, Lewis et al. 1984, Swindel et al. 1986), notably among selected genera including the *Rhynschospora* (sedges), small panic grasses (*Dichanthelium* spp.), *Eupatorium* spp, and bluestems, all genera that increased in herbicide treatments in our study. These genera among others are recognized as ruderal species able to respond quickly to available resources. One other group, ferns, increased significantly with bedding/mounding in the second year. Bracken, which dominates the fern cover on our sites, resprouts readily after bedding (Lauer & Zutter 2001).

Chemical treatment effects on abundance

Chemical treatments immediately reduced the shrub component to about a third of the cover in non-herbicide treatments (32% in non-herbicide treatments compared to 11% in herbicide treatments). Although the shrubs in chemically treated sites began to recover in the second year, the difference between chemical and non-chemical treatments persisted after burning, suggesting that there was a reduction in shrub root crowns in addition to reduced growth rates. Miller and Chamberlain (2008) report similar effects on yaupon (*Ilex vomitoria*), an evergreen holly similar to *Ilex glabra* that is common on our plots. With no further treatments, however, the shrub reduction is expected to be a short term effect (<4 years; Lauer & Glover 1995, Zutter et al. 1986, Miller & Chamberlain 2008). Although the imazapyr and triclopyr formulation targeted woody competitors, effects on other species from other growth forms have been previously reported. We interpret immediate post-treatment reductions (2004 results) as direct negative impacts on large grasses, forbs and woody vines, and as others have found, the effects were transient (Zhao et al. 2008). Recovery may have been facilitated by the increased availability of resources following woody vegetation reduction (Zutter & Miller 1998, Miller et al. 1995). In contrast, the small graminoid and fern groups showed no immediate reductions by the chemical treatment, suggesting a resistance to the formulation used, and increased cover beginning the year after treatments. The small graminoid group includes species that can rapidly respond to increased resource availability; that is, they have been shown to increase with various forms of disturbance that reduce competition. For example, *Rhynchopsora* spp. and *Dichanthelium* spp. are both reported to increase with intensive mechanical site preparation involving disking and double bedding (Conde et al. 1983b) and were found to increase with herbicide treatment in our study (Table 3.4.7).

Responses to herbicides varied within groups, notably among large grasses. We found overall negative effects of herbicide treatments on wiregrass but increases in chalky bluestem. Positive growth responses by blustems subjected to imazapyr and triclopyr applications have been previously noted (Miller and Chamberlain 2008, Litt et al. 2001),

and suggest its ability to respond to increased resources. In contrast, wiregrass is considered a stress-tolerant species (*sensu* Grime 1979) that is negatively affected when resources are increased, whether by fertilization (White 1977) or a reduction in competition as seen in this study. Ecologically, these two species are quite distinct, and their dominance within a site typically indicates different site conditions and/or history. In frequently burned flatwoods, wiregrass is the dominant bunch grass and produces highly flammable fuels that burn readily even shortly after rain events. Chalky bluestem dominates disturbed, lower quality natural areas, and compared to wiregrass provides less reliable fine fuels that may reduce the likelihood of frequent fires needed to perpetuate the characteristic ground layer diversity.

Effects of fire

The vegetation responses seen in the 2006 data are a result of both treatment effects and their interaction with a prescribed fire that occurred in all of the experimental blocks in March 2006. The effect of fire was to remove most of the aboveground biomass that had accumulated since the previous fire (December 2004; prior to site preparation). Shrubs, the most abundant growth form on the sites, and one capable of increasing in size every year, were reduced to root crowns. Differences in shrub cover at the end of 2006 show that the herbicide treatment did reduce either the number or vigor of residual shrubs. It is likely that reductions in shrub abundance from site preparation will be maintained by continued regular prescribed burning.

The positive effect of herbicide treatments on total herbaceous cover in 2006 may be an indirect effect of nutrients released after burning. Fires result in a pulse of nutrients to the system, but this pulse is often short-lived as nutrients are taken up quickly by re-growing vegetation (Christensen 1977, 1993). Where shrub cover was lowest in 2005, the herbaceous cover in 2006 was greatest (Figures 3.4.6, 3.4.7); we hypothesize that herbaceous vegetation rapidly captured available nutrients that otherwise would have been taken up by dominant shrubs. This hypothesis is consistent with 2006 treatment patterns: where herbaceous cover was highest, woody cover was lowest. By 2006, all herbaceous groups appeared to benefit in some way from the herbicide treatments (Figure 3.4.10), though the effect was not significant for large graminoids and forbs. A careful look at the large graminoid response shows that the cover of large graminoids in herbicide treatments increased while cover in the F and CF plots decreased after burning. We attribute the F and CF decrease to a reduction in the size of grass crowns and slow regrowth, in contrast to the rapid regrowth in the sites that had herbicide treatments, presumably as a result of reduced competition from shrubs for available resources post-fire, as hypothesized. In summary, shrub reduction in combination with prescribed fire effectively redistributed resources from woody to herbaceous vegetation (Zhao et al. 2008). An increase in herbaceous cover is a desirable effect, in that the increase in herbaceous cover approaches the desired 40% herbaceous cover identified in the RCW Recovery plan as suitable habitat (US FWS 2003).

Patterns in species richness

Differences in species richness were associated with effects of herbicide application with little evidence of change from bedding or mounding. Knapp et al. (2008) reported decreased species cover on top of beds and mounds; some mounds were nearly devoid of plants other than the planted seedling (species richness equals one per square meter) for two growing seasons. The mean from samples distributed throughout the area, including beds, mounds, and areas in between, resulted in no detectable plot level differences. The mechanical effect at the smallest sample scale (0.1 m^2) may be related to the localized disturbance of bedding and mounding, and such small areas are likely to be re-vegetated from invading rhizomes or local seed sources. Unlike the localized effects of beds or mounds, the broadcast chemical application would have produced a more uniform effect with smaller variance and more reliably detected treatment differences.

Total species richness in herbicide treatments was reduced compared to non-herbicide treatments at the smallest and largest scales, but the analysis of shrub and forb richness (groups with the largest numbers of species) indicates that the treatment differences were largely a result of the effects on shrubs. While herbicides reduced shrub richness, there was no treatment effect on the herbaceous vegetation. Forbs, the group with the largest number of species, increased from year to year. This increase along with the continuous increase in species richness of the flat check (F) plots suggest that richness in the study area may not have been in equilibrium at the time of treatments. Small scale species richness is somewhat variable from year to year in response to annual rainfall, but also may vary with recent management history. The study areas had received several management actions, including harvest, shearing, and burning, prior to site preparation for this study. Any of these may affect small scale species richness, and different vegetation components may change at different rates. For example, Swindel et al. (1986) reported that the shrub component in a site-prepared flatwoods site approached pre-treatment conditions within several years, while the herbaceous component showed no tendency to converge even after eight. Continued monitoring will be needed to determine whether treatments in our study have changed the trajectories of vegetation development.

All in all the richness of flatwoods ground layer vegetation at the scale of 100 m^2 or larger is remarkably unchanged by the moderate site preparation treatments used in this study. No exotic invasive species appeared in the treated plots, and no species were eliminated. The results reported here show only vegetation change through three seasons. Previous studies have shown that vegetation continues to change through plantation development, especially following the effects of tree canopy closure (e.g. reduced light, lower soil moisture and water table, and deeper litter and forest floor layers). The distribution of characteristic flatwoods species are related to soil moisture gradients (Peet 2006), and an accumulation of litter and duff has been implicated in the slow recovery of herbs in some upland longleaf pine restoration efforts (Hiers et al. 2007).

3.4.5. Conclusions

1. Bedding or mounding as applied in this study should have no short-term adverse effect on ground layer vegetation cover, richness or composition for the first few years. No

species were lost, and no aggressive exotic species were gained in bedded or mounded treatments.

2. The herbicide formulation used in this study (imazapyr and triclopyr) and broadcast prior to planting longleaf pine seedlings effectively reduced woody plant cover, and had no lasting effects on other plant groups.

3. There was a tendency for all herbaceous groups to benefit from the herbicide effect of reducing the shrubby dominance. Shrubs were not eliminated by this treatment, but herbaceous cover tended to increase by the third year after site preparation.

4. Prescribed burning appears to be critical for maintaining any benefits to the herbaceous community. A diverse herbaceous layer has been recognized as an essential characteristic of high quality red-cockaded woodpecker habitat.

5. Although the plant community richness or abundance was not changed much by site preparation in the first 3 years after treatment, the beds and troughs produced by bedding are expected to persist throughout the age of the plantation (Schultz 1976). Through time, these features will change the microhabitats within the flatwoods, creating both drier and wetter than average conditions that are likely to favor different vegetation. Such changes have been noted, specifically the increase in shrubs or low panicums on the beds and sedges and rushes in the wet troughs (Swindel et al. 1982).

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Tables

Table 3.4.1. ANOVA for testing effects of all study treatments, treatments including herbicide, and treatments including mechanical site preparation (i.e. bedding or mounding) on cover and richness of total ground layer vegetation in 2004, 2005, and 2006

		Treatment effect		Herbicide effect		Mechanical effect	
Year	Variable	F-statistic	*p-value*	F-statistic	*p-value*	F-statistic	*p-value*
2004	Cover	15.22	<0.0001	68.42	<0.0001	7.42	0.0110
	Richness	11.51	<0.0001	71.36	<0.0001	4.80	0.0370
2005	Cover	15.27	<0.0001	74.97	<0.0001	8.64	0.0065
	Richness	6.07	0.0002	23.18	<0.0001	0.31	0.5815
2006	Cover	4.27	0.0025	15.51	0.0005	0.14	0.7102
	Richness	2.11	0.0761	10.08	0.0036	0.22	0.6400

Table 3.4.2. ANOVA for testing effects of all study treatments, treatments including herbicide, and treatments including mechanical site preparation (i.e. bedding or mounding) on cover and richness of herbaceous and woody ground layer vegetation in 2004, 2005, and 2006

			Treatment effect		Herbicide effect		Mechanical effect	
Year	Group	Variable	F-statistic	*p-value*	F-statistic	*p-value*	F-statistic	*p-value*
2004	Herbaceous	Cover	1.80	0.1269	5.89	0.0219	1.22	0.2791
		Richness	1.98	0.0934	7.39	0.0111	2.76	0.1079
	Woody	Cover*	14.18	<0.0001	72.07	<0.0001	6.19	0.0190
		Richness	32.93	<0.0001	221.19	<0.0001	3.29	0.0806
2005	Herbaceous	Cover	2.10	0.0771	0.50	0.4844	0.00	0.9704
		Richness	1.95	0.0980	0.13	0.7252	0.10	0.7578
	Woody	Cover**	19.86	<0.0001	116.00	<0.0001	8.06	0.0083
		Richness	12.42	<0.0001	78.96	<0.0001	0.26	0.6154
2006	Herbaceous	Cover	2.85	0.0223	10.07	0.0036	0.01	0.9207
		Richness	0.95	0.4865	1.58	0.2193	0.46	0.5044
	Woody	Cover	6.82	<0.0001	36.62	<0.0001	0.03	0.8715
		Richness	16.86	<0.0001	112.48	<0.0001	1.28	0.2673

*Data analyzed following square root transformation
**Data analyzed following log(x+1) transformation

Table 3.4.3. ANOVA for testing effects of all study treatments and treatments including herbicide on cover and richness of ground layer vegetation by functional group in 2004

2004		Treatment effect		Herbicide effect		Mechanical effect	
Group	Variable	F-statistic	*p-value*	F-statistic	*p-value*	F-statistic	*p-value*
Large graminoids	Cover	6.11	0.0002	34.33	<0.0001	2.90	0.0998
	Richness	4.68	0.0014	21.43	<0.0001	3.07	0.0906
Small graminoids	Cover	0.70	0.6747	0.83	0.3697	0.52	0.4757
	Richness	0.10	0.9976	0.09	0.7669	0.42	0.5200
Forbs	Cover	2.47	0.0418	12.45	0.0015	0.61	0.4426
	Richness	2.01	0.0880	11.36	0.0022	1.59	0.2184
Ferns	Cover*	2.13	0.0727	4.00	0.0552	0.42	0.5216
	Richness	1.56	0.1883	2.09	0.1591	0.14	0.7083
Shrubs	Cover**	11.81	<0.0001	60.61	<0.0001	6.11	0.0198
	Richness	26.24	<0.0001	176.50	<0.0001	1.66	0.2076
Vines	Cover*	4.30	0.0024	24.46	<0.0001	0.08	0.7763
	Richness	5.74	0.0003	35.34	<0.0001	2.26	0.1440

*Data analyzed following log(x+1) transformation

**Data analyzed following square root transformation

Table 3.4.4. ANOVA for testing effects of all study treatments and treatments including herbicide on cover and richness of ground layer vegetation by functional group in 2005

2005		Treatment effect		Herbicide effect		Mechanical effect	
Group	Variable	F-statistic	*p-value*	F-statistic	*p-value*	F-statistic	*p-value*
Large graminoids	Cover	3.33	0.0105	17.22	0.0003	2.34	0.1375
	Richness	4.78	0.0012	14.15	0.0008	12.21	0.0016
Small graminoids	Cover	5.33	0.0006	17.26	0.0003	0.10	0.7572
	Richness	6.85	<0.0001	29.06	<0.0001	2.49	0.1255
Forbs	Cover	0.60	0.7511	0.07	0.7906	0.61	0.4401
	Richness	1.28	0.2953	0.99	0.3277	0.25	0.6180
Ferns	Cover	2.43	0.0447	5.70	0.0239	2.43	0.1304
	Richness	1.41	0.2406	1.94	0.1745	0.39	0.5399
Shrubs	Cover	9.03	<0.0001	51.22	<0.0001	5.19	0.0305
	Richness	12.09	<0.0001	79.53	<0.0001	1.60	0.2169
Vines	Cover	2.77	0.0255	9.75	0.0041	3.29	0.0804
	Richness	2.11	0.0752	2.99	0.0949	0.83	0.3703

Table 3.4.5. ANOVA for testing effects of all study treatments and treatments including herbicide on cover and richness of ground layer vegetation by functional group in 2006

2006		Treatment effect		Herbicide effect		Mechanical effect	
Group	Variable	F-statistic	*p-value*	F-statistic	*p-value*	F-statistic	*p-value*
Large graminoids	Cover	1.42	0.2367	3.69	0.0651	4.15	0.0512
	Richness	1.02	0.4395	0.11	0.7394	3.98	0.0558
Small graminoids	Cover	1.82	0.1236	6.50	0.0165	1.73	0.1989
	Richness	1.82	0.1222	0.18	0.6769	0.52	0.4763
Forbs	Cover	0.71	0.6610	0.72	0.4048	0.01	0.9302
	Richness	0.56	0.7799	0.98	0.3313	0.00	0.9818
Ferns	Cover	2.57	0.0353	7.37	0.0112	0.16	0.6913
	Richness	2.48	0.0412	5.62	0.0249	0.38	0.5429
Shrubs	Cover	6.22	0.0002	34.28	<0.0001	0.00	0.9494
	Richness	15.66	<0.0001	107.02	<0.0001	1.27	0.2702
Vines	Cover	0.76	0.6265	1.81	0.1897	0.08	0.7759
	Richness	2.37	0.0488	4.08	0.0531	0.03	0.8669

Table 3.4.6. ANOVA for testing effects of all study treatments and treatments including herbicide on cover and richness of selected ground layer species in 2006

			Treatment effect		Herbicide effect	
Rank	Species	Variable	F-statistic	*p-value*	F-statistic	*p-value*
1	dichsp.	Frequency	0.38	0.9038	0.10	0.7585
		Cover	1.04	0.4261	5.13	0.0314
2	vaccra	Frequency	2.22	0.0588	2.62	0.1157
		Cover	0.78	0.6121	0.84	0.3660
3	andcap	Frequency	7.12	<0.0001	46.47	<0.0001
		Cover	6.92	<0.0001	44.84	<0.0001
4	rhysp.	Frequency*	1.48	0.2146	3.87	0.0591
		Cover*	0.95	0.4836	3.39	0.0763
5	aroarb	Frequency	5.01	0.0009	32.29	<0.0001
		Cover	7.46	<0.0001	34.12	<0.0001
6	ilegla	Frequency*	2.47	0.0415	14.76	0.0006
		Cover*	1.84	0.1196	6.72	0.0150
7	gayfro	Frequency	3.82	0.0049	16.42	0.0004
		Cover	4.44	0.0020	27.67	<0.0001
8	ptraqu	Frequency	0.84	0.5664	2.04	0.1627
		Cover	1.54	0.1956	5.47	0.0267
9	schsch	Frequency	0.62	0.7358	2.04	0.1640
		Cover	1.21	0.3285	2.99	0.0947
10	aristr	Frequency	6.28	0.0002	28.21	<0.0001
		Cover	7.69	<0.0001	48.68	<0.0001
11	pollut	Frequency	1.88	0.1106	7.55	0.0104
		Cover*	1.69	0.1526	4.97	0.0341
12	xyrsp.	Frequency	1.03	0.4305	2.11	0.1575
		Cover	0.86	0.5464	0.70	0.4086
13	smilau	Frequency	1.63	0.1685	0.21	0.6486
		Cover	0.90	0.5231	0.02	0.8785
14	perbor	Frequency	5.23	0.0007	29.37	<0.0001
		Cover*	4.37	0.0022	23.84	<0.0001
15	eupsp	Frequency	5.14	0.0008	8.79	0.0061
		Cover**	5.16	0.0007	5.71	0.0238
16	gaydum	Frequency	5.60	0.0004	24.52	<0.0001
		Cover**	6.11	0.0001	26.41	<0.0001
17	rhepet	Frequency*	1.01	0.4472	0.18	0.6733
		Cover*	1.39	0.2479	1.23	0.2776
18	laccar	Frequency*	1.19	0.3424	0.01	0.9070
		Cover*	1.84	0.1193	0.77	0.3880
19	lyomar	Frequency	1.55	0.1931	2.76	0.1077
		Cover	1.08	0.4040	2.08	0.1602
20	vacten	Frequency	6.82	<0.0001	23.39	<0.0001
		Cover**	6.79	<0.0001	25.36	<0.0001

*Data analyzed following square root transformation

**Data analyzed following log(x+1) transformation

Table 3.4.7. Means of cover and relative frequency of common herbaceous species in response to herbicide treatments

Rank	Species	Variable	Herbicide	No herbicide
1	dichsp.	Frequency	67.1	64.7
		Cover*	74.3[a]	40.1[b]
2	vaccra	Frequency	56.2	67.4
		Cover	52.8	65.6
3	andcap	Frequency	78.8[a]	39.7[b]
		Cover	106.6[a]	29.3[b]
4	rhysp.	Frequency*	58.8	46.4
		Cover*	29.8	18.3
5	aroarb	Frequency	29.2[b]	64.4[a]
		Cover	11.35[b]	51.6[a]
6	ilegla	Frequency*	35.4[b]	57.4[a]
		Cover*	39.2[b]	76.3[a]
7	gayfro	Frequency	35.4[b]	56.1[a]
		Cover	28.0[b]	71.5[b]
8	ptraqu	Frequency	45.8	34.6
		Cover	70[a]	32.7[b]
9	schsch	Frequency	40.8	31.5
		Cover	29.6	18.5
10	aristr	Frequency	22.5[b]	49.2[a]
		Cover	24.3[b]	72.9[a]
11	pollut	Frequency	42.9[a]	25.5[b]
		Cover*	13.5[a]	8.9[b]
12	xyrsp.	Frequency	28.7	37.7
		Cover	10.6	13.1
13	smilau	Frequency	32.1	29.3
		Cover	21.3	22.7
14	perbor	Frequency	14.2[b]	43.3[a]
		Cover*	12.1[b]	53.7[a]
15	eupsp	Frequency	29.6[a]	17.0[b]
		Cover**	13.4[a]	5.0[b]
16	gaydum	Frequency	11.7[b]	29.7[a]
		Cover**	4.2[b]	18.5[a]
17	rhepet	Frequency*	20.8	19.2
		Cover*	8.2	5.8
18	laccar	Frequency*	19.2	18
		Cover*	15.3	9.8
19	lyomar	Frequency	12.1	20.1
		Cover	4.3	7.3
20	vacten	Frequency	7.5[b]	23.2[a]
		Cover**	2.3[b]	15.8[a]

*Data analyzed following square root transformation

**Data analyzed following log(x+1) transformation

Table 3.4.8. Results of repeated measures ANOVA tests on species richness at different scales

Scale	Effect	F-statistic	*p-value*
0.1 m^2	Treatment	3.32	0.0034
	Year	10.21	<0.0001
	Treatment* year	0.67	0.7952
	Herbicide	9.11	0.0033
	Mechanical	7.06	0.0093
1 m^2	Treatment	2.70	0.0138
	Year	10.06	0.0001
	Treatment* year	1.07	0.3984
	Herbicide	1.17	0.2830
	Mechanical	3.19	0.0774
10 m^2	Treatment	2.16	0.0446
	Year	4.30	0.0164
	Treatment* year	0.57	0.8848
	Herbicide	1.99	0.1612
	Mechanical	0.05	0.8181
100 m^2	Treatment	3.24	0.0041
	Year	6.67	0.0020
	Treatment* year	1.17	0.3151
	Herbicide	12.10	0.0008
	Mechanical	0.07	0.7991

Table 3.4.9. Results of repeated measures ANOVA tests on species richness of forbs at different scales

Scale	Effect	F-statistic	*p-value*
	Treatment	1.36	0.2297
	Year	5.09	0.0080
0.1 m^{2*}	Treatment* year	0.73	0.7437
	Herbicide	0.51	0.4749
	Mechanical	1.32	0.2538
	Treatment	0.64	0.7250
	Year	6.30	0.0027
1 m^{2**}	Treatment* year	0.44	0.9572
	Herbicide	0.31	0.5804
	Mechanical	0.37	0.5467
	Treatment	0.85	0.5503
	Year	4.89	0.0096
10 m^2	Treatment* year	0.68	0.7920
	Herbicide	0.00	0.9449
	Mechanical	0.05	0.8214
	Treatment	1.49	0.1795
	Year	6.73	0.0019
100 m^2	Treatment* year	0.95	0.5077
	Herbicide	2.87	0.0937
	Mechanical	0.01	0.9389

*Data analyzed following square root transformation

**Data analyzed following log(x+1) transformation

Table 3.4.10. Results of repeated measures ANOVA tests on species richness of shrubs at different scales

Scale	Effect	F-statistic	*p-value*
$0.1\ m^2$	Treatment	6.44	<0.0001
	Year	1.71	0.1870
	Treatment* year	1.11	0.3596
	Herbicide	33.95	<0.0001
	Mechanical	10.20	0.0019
$1\ m^2$	Treatment	6.17	<0.0001
	Year	1.63	0.2020
	Treatment* year	0.85	0.6116
	Herbicide	25.74	<0.0001
	Mechanical	1.14	0.2879
$10\ m^2$	Treatment	6.38	<0.0001
	Year	0.36	0.6961
	Treatment* year	0.81	0.6519
	Herbicide	27.24	<0.0001
	Mechanical	0.32	0.5726
$100\ m^{2*}$	Treatment	9.17	<0.0001
	Year	1.50	0.2285
	Treatment* year	0.84	0.6201
	Herbicide	56.12	<0.0001
	Mechanical	0.15	0.6955

*Data analyzed following log(x+1) transformation

Figures

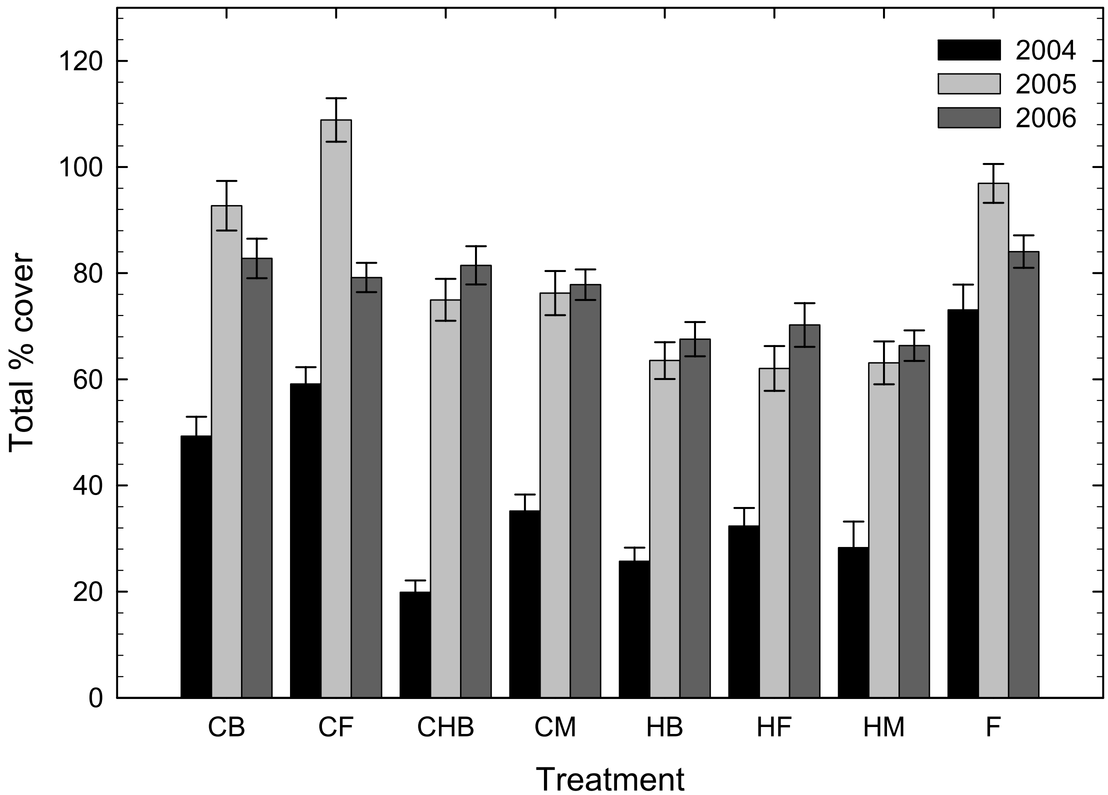

Figure 3.4.1. Total percent cover of ground layer vegetation by treatment for each year. Treatments are as follows: CB = chopping and bedding, CF = chopping and flat-planting, CHB = chopping, herbicide, and bedding, CM = chopping and mounding, HB = herbicide and bedding, HF = herbicide and flat-planting, HM = herbicide and mounding, F = flat-planting only (control).

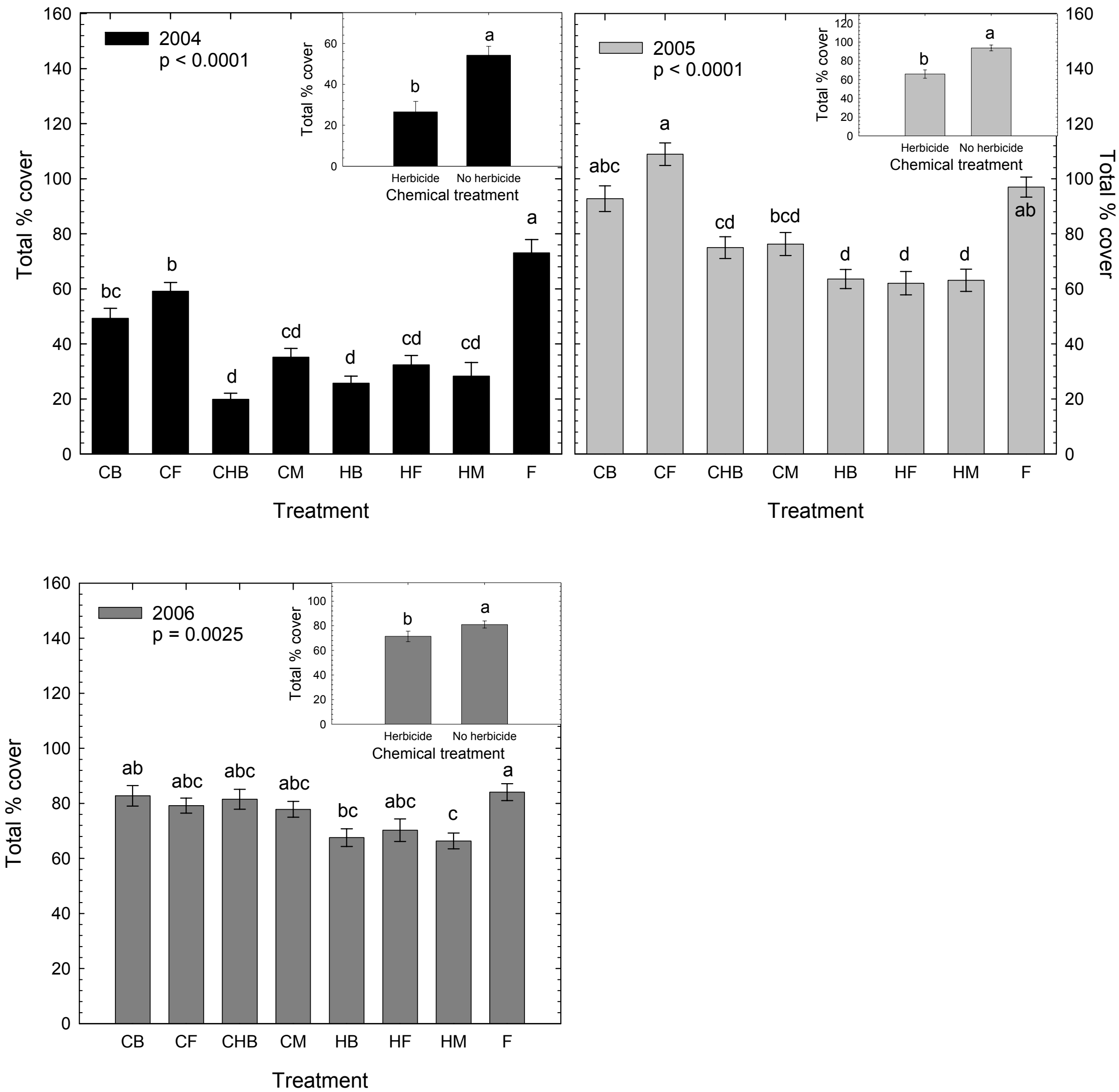

Figure 3.4.2. Total percent cover of ground layer vegetation by treatment for each year. Similar letters within a figure indicate no significant differences. Treatments are as follows: CB = chopping and bedding, CF = chopping and flat-planting, CHB = chopping, herbicide, and bedding, CM = chopping and mounding, HB = herbicide and bedding, HF = herbicide and flat-planting, HM = herbicide and mounding, F = flat-planting only (control). Inset: Contrast of treatments with herbicide (CHB, HB, HF, HM) vs. treatments with no herbicide (CB, CF, CM, F).

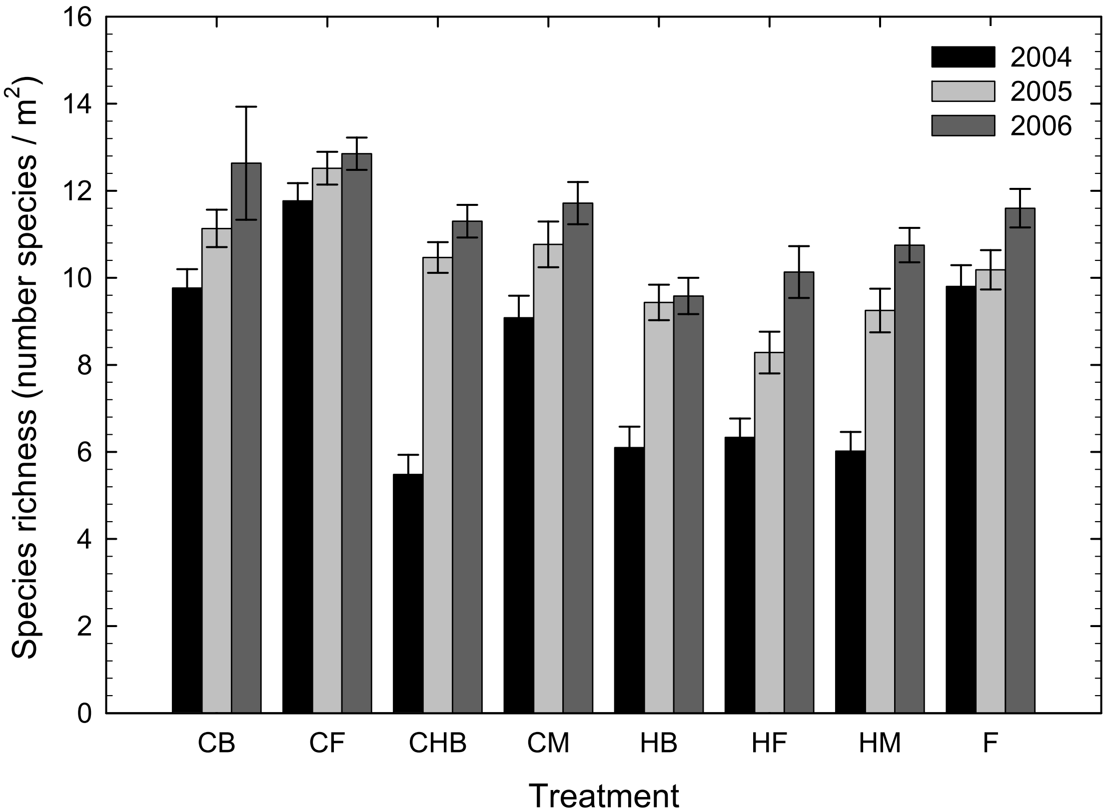

Figure 3.4.3. Species richness of ground layer vegetation by treatment for each year. Treatments are as follows: CB = chopping and bedding, CF = chopping and flat-planting, CHB = chopping, herbicide, and bedding, CM = chopping and mounding, HB = herbicide and bedding, HF = herbicide and flat-planting, HM = herbicide and mounding, F = flat-planting only (control).

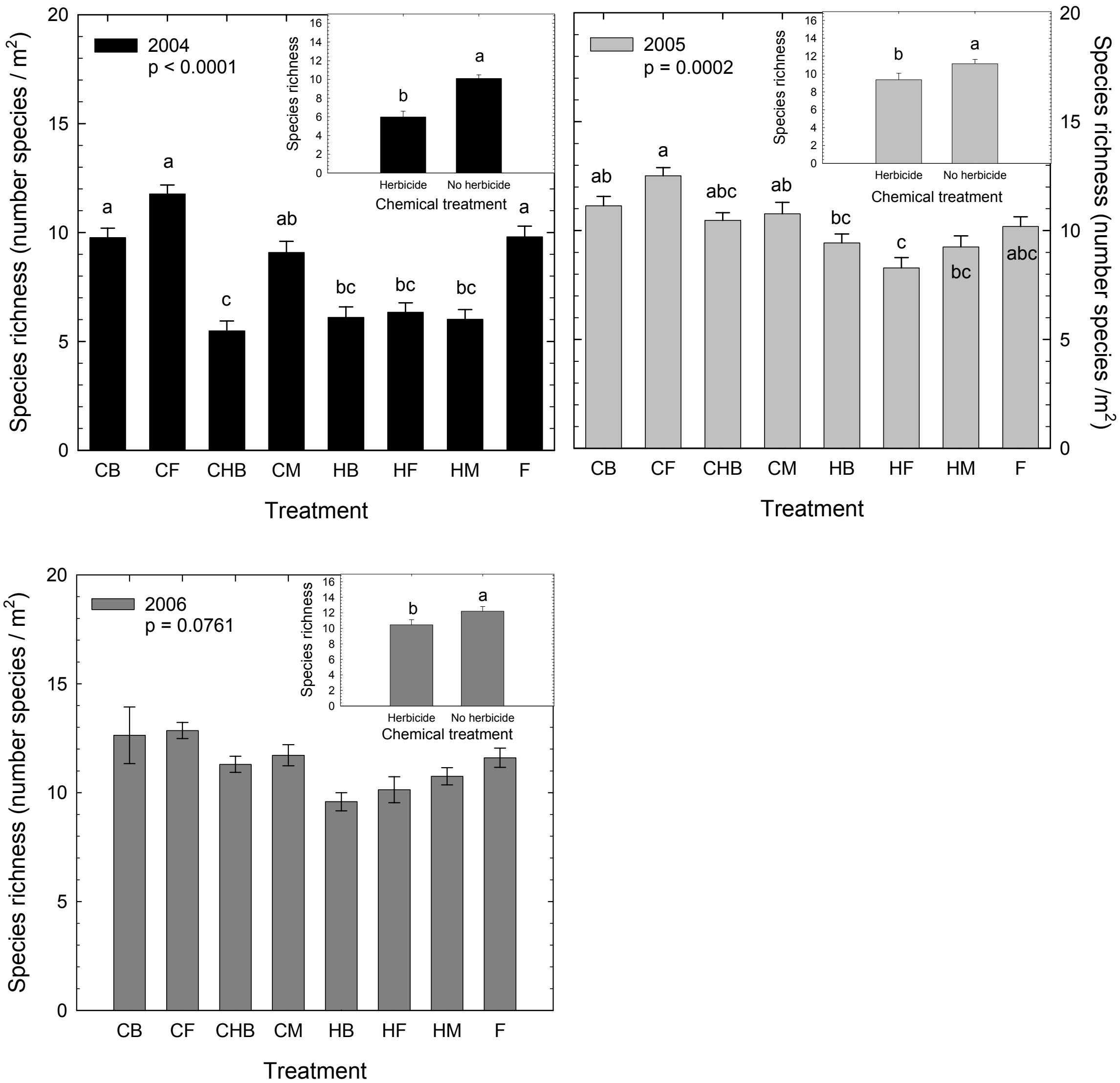

Figure 3.4.4. Species richness of ground layer vegetation by treatment for each year. Similar letters within a figure indicate no significant differences. Treatments are as follows: CB = chopping and bedding, CF = chopping and flat-planting, CHB = chopping, herbicide, and bedding, CM = chopping and mounding, HB = herbicide and bedding, HF = herbicide and flat-planting, HM = herbicide and mounding, F = flat-planting only (control). Inset: Contrast of treatments with herbicide (CHB, HB, HF, HM) vs. treatments with no herbicide (CB, CF, CM, F).

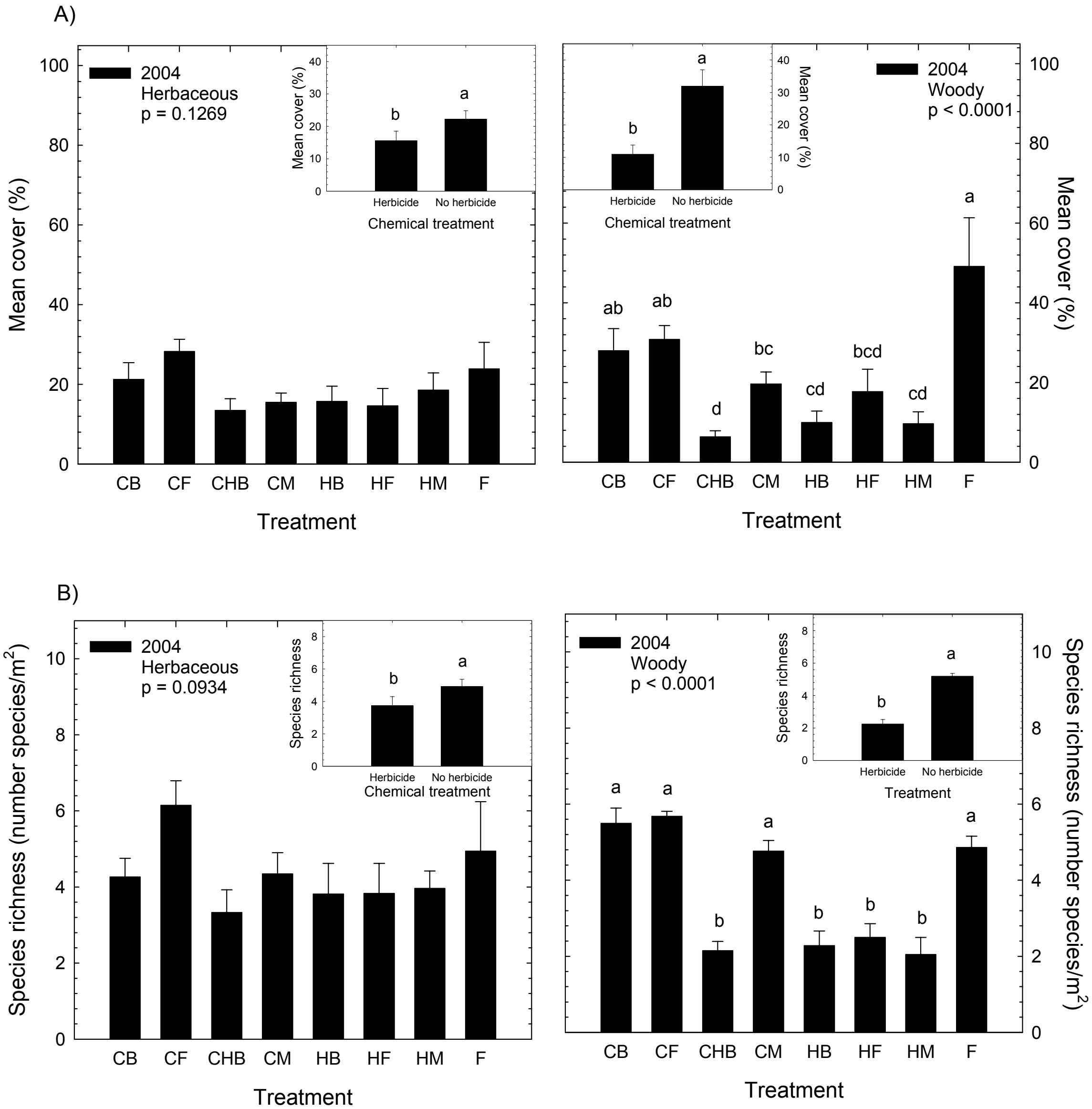

Figure 3.4.5. Percent cover (A) and species richness (B) of woody and herbaceous ground layer vegetation by treatment in 2004. Similar letters within a figure indicate no significant differences. Treatments are as follows: CB = chopping and bedding, CF = chopping and flat-planting, CHB = chopping, herbicide, and bedding, CM = chopping and mounding, HB = herbicide and bedding, HF = herbicide and flat-planting, HM = herbicide and mounding, F = flat-planting only (control). Inset: Contrast of treatments with herbicide (CHB, HB, HF, HM) vs. treatments with no herbicide (CB, CF, CM, F).

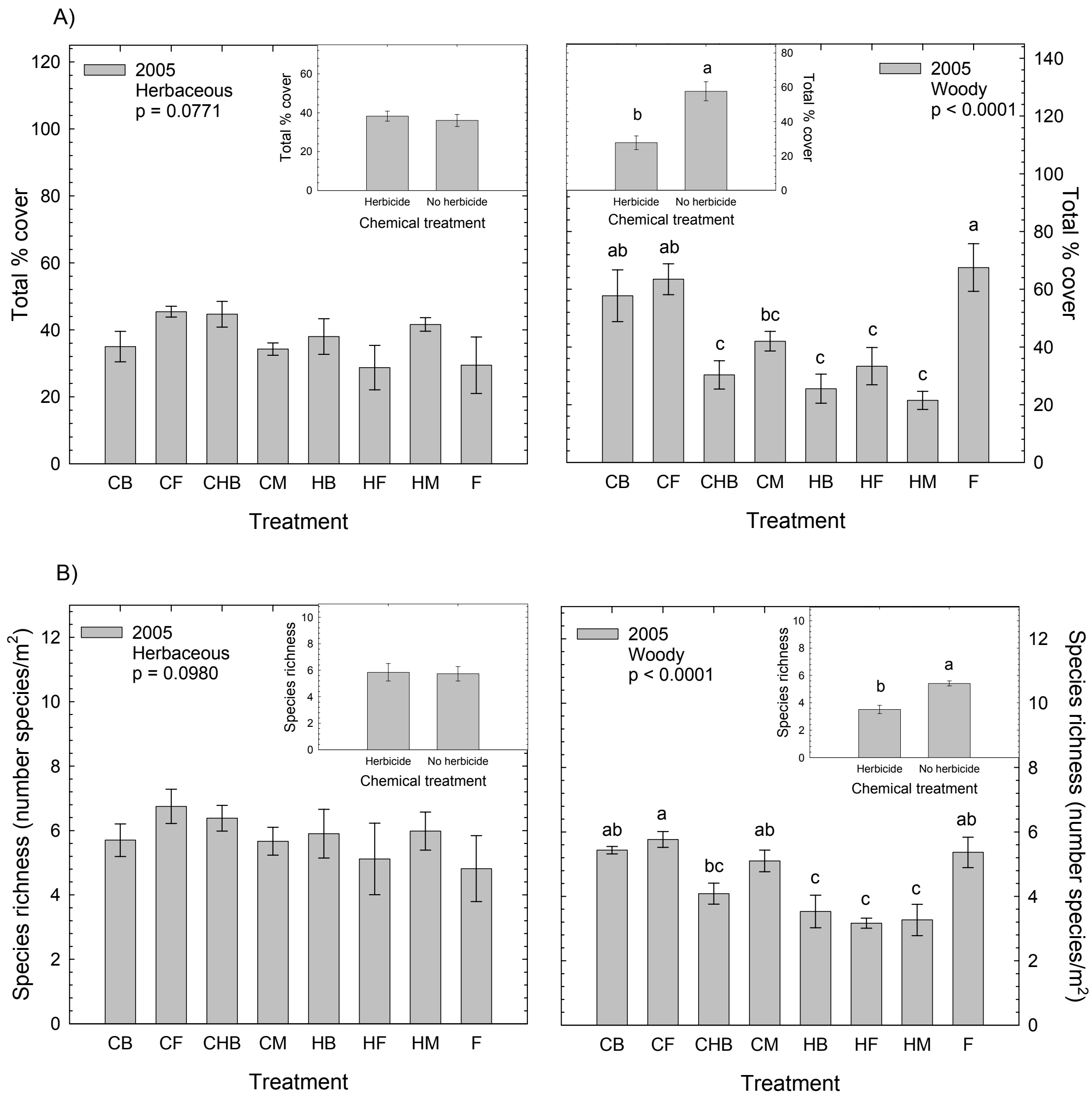

Figure 3.4.6. Percent cover (A) and species richness (B) of woody and herbaceous ground layer vegetation by treatment in 2005. Similar letters within a figure indicate no significant differences. Treatments are as follows: CB = chopping and bedding, CF = chopping and flat-planting, CHB = chopping, herbicide, and bedding, CM = chopping and mounding, HB = herbicide and bedding, HF = herbicide and flat-planting, HM = herbicide and mounding, F = flat-planting only (control). Inset: Contrast of treatments with herbicide (CHB, HB, HF, HM) vs. treatments with no herbicide (CB, CF, CM, F).

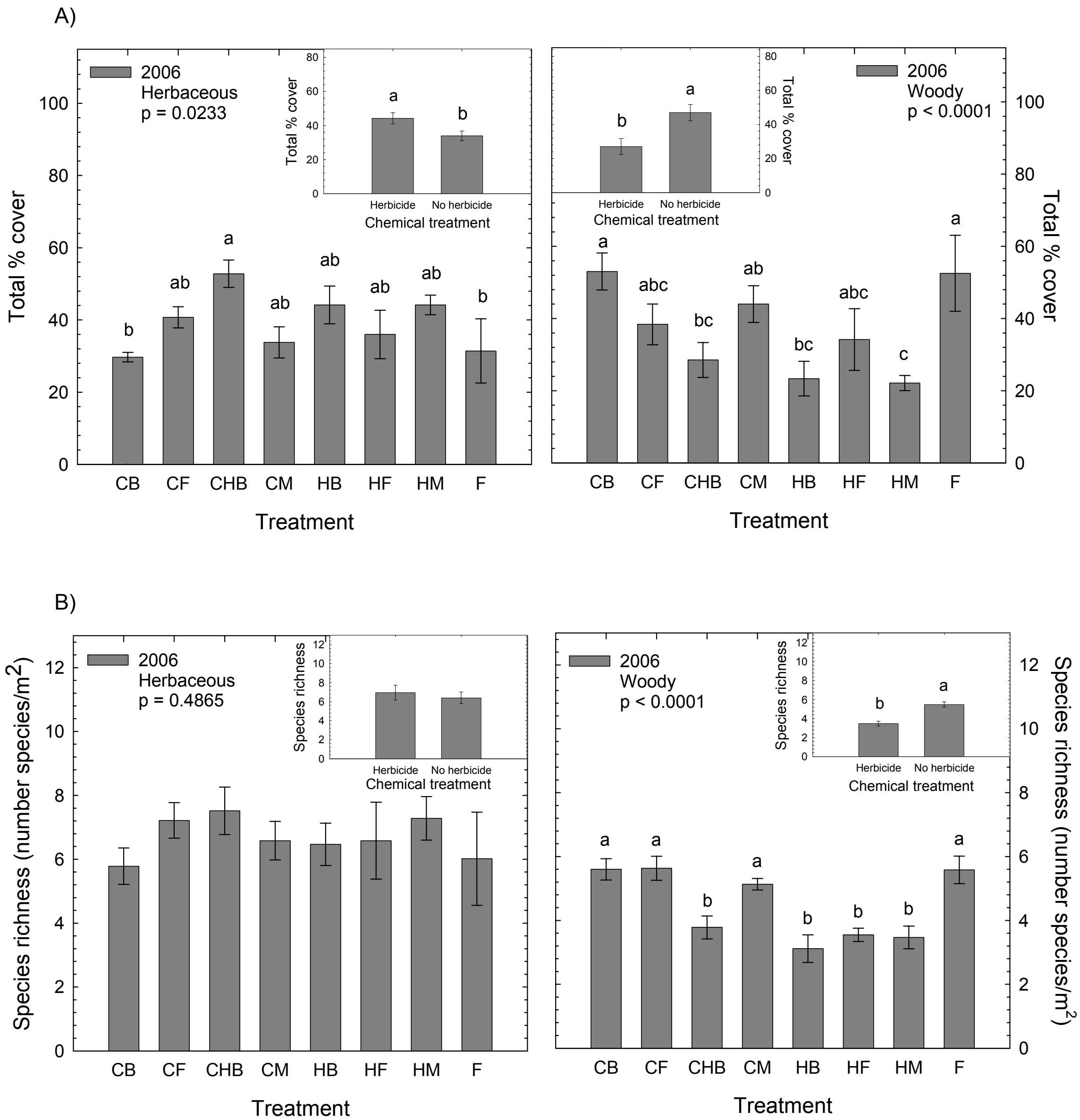

Figure 3.4.7. Percent cover (A) and species richness (B) of woody and herbaceous ground layer vegetation by treatment in 2006. Similar letters within a figure indicate no significant differences. Treatments are as follows: CB = chopping and bedding, CF = chopping and flat-planting, CHB = chopping, herbicide, and bedding, CM = chopping and mounding, HB = herbicide and bedding, HF = herbicide and flat-planting, HM = herbicide and mounding, F = flat-planting only (control). Inset: Contrast of treatments with herbicide (CHB, HB, HF, HM) vs. treatments with no herbicide (CB, CF, CM, F).

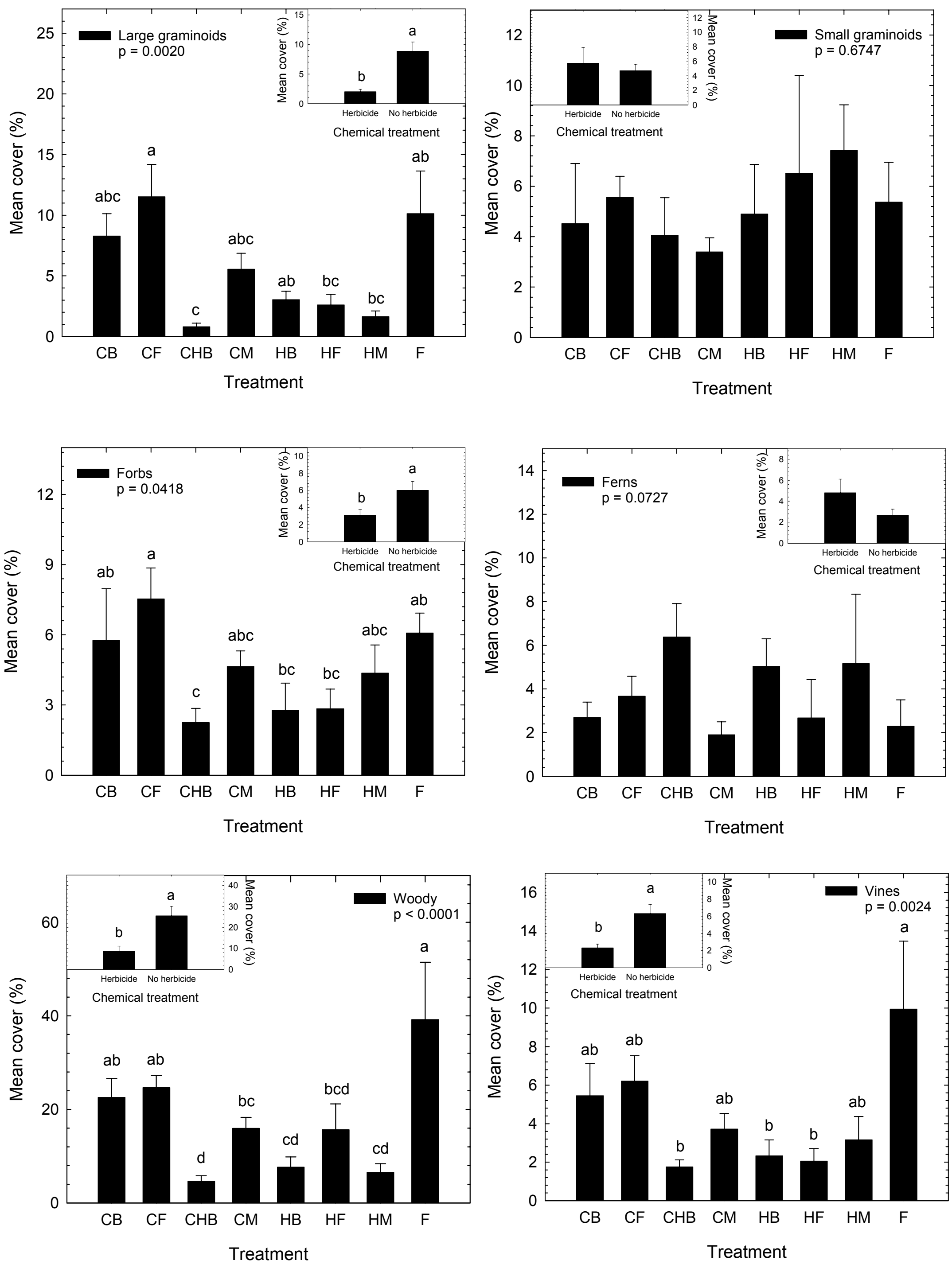

Figure 3.4.8. Percent cover of ground layer vegetation for each functional group by treatment in 2004. Similar letters within a figure indicate no significant differences. Inset: Contrast of treatments with herbicide (CHB, HB, HF, HM) vs. treatments with no herbicide (CB, CF, CM, F).

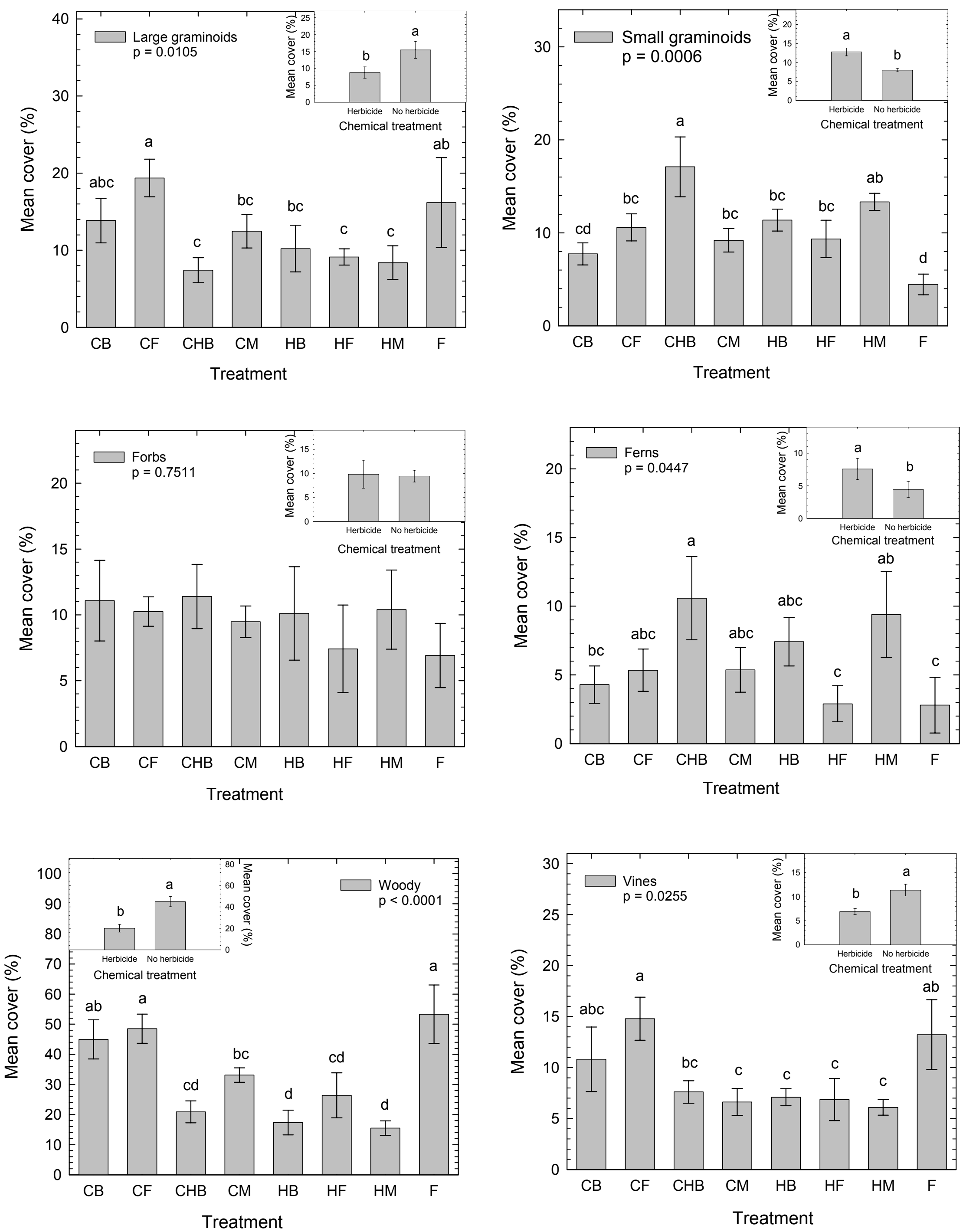

Figure 3.4.9. Percent cover of ground layer vegetation for each functional group by treatment in 2005. Similar letters within a figure indicate no significant differences. Inset: Contrast of treatments with herbicide (CHB, HB, HF, HM) vs. treatments with no herbicide (CB, CF, CM, F).

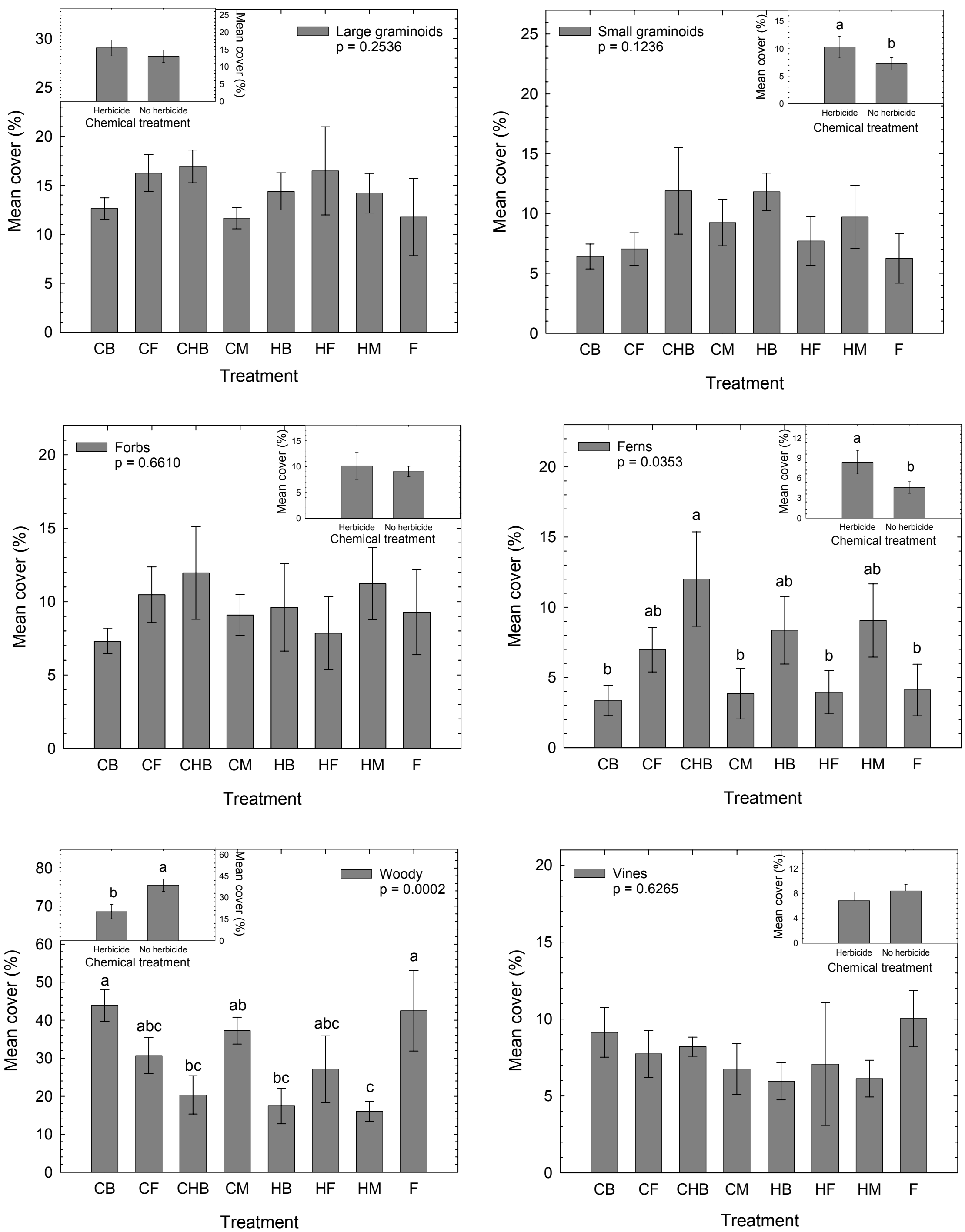

Figure 3.4.10. Percent cover of ground layer vegetation for each functional group by treatment in 2006. Similar letters within a figure indicate no significant differences. Inset: Contrast of treatments with herbicide (CHB, HB, HF, HM) vs. treatments with no herbicide (CB, CF, CM, F).

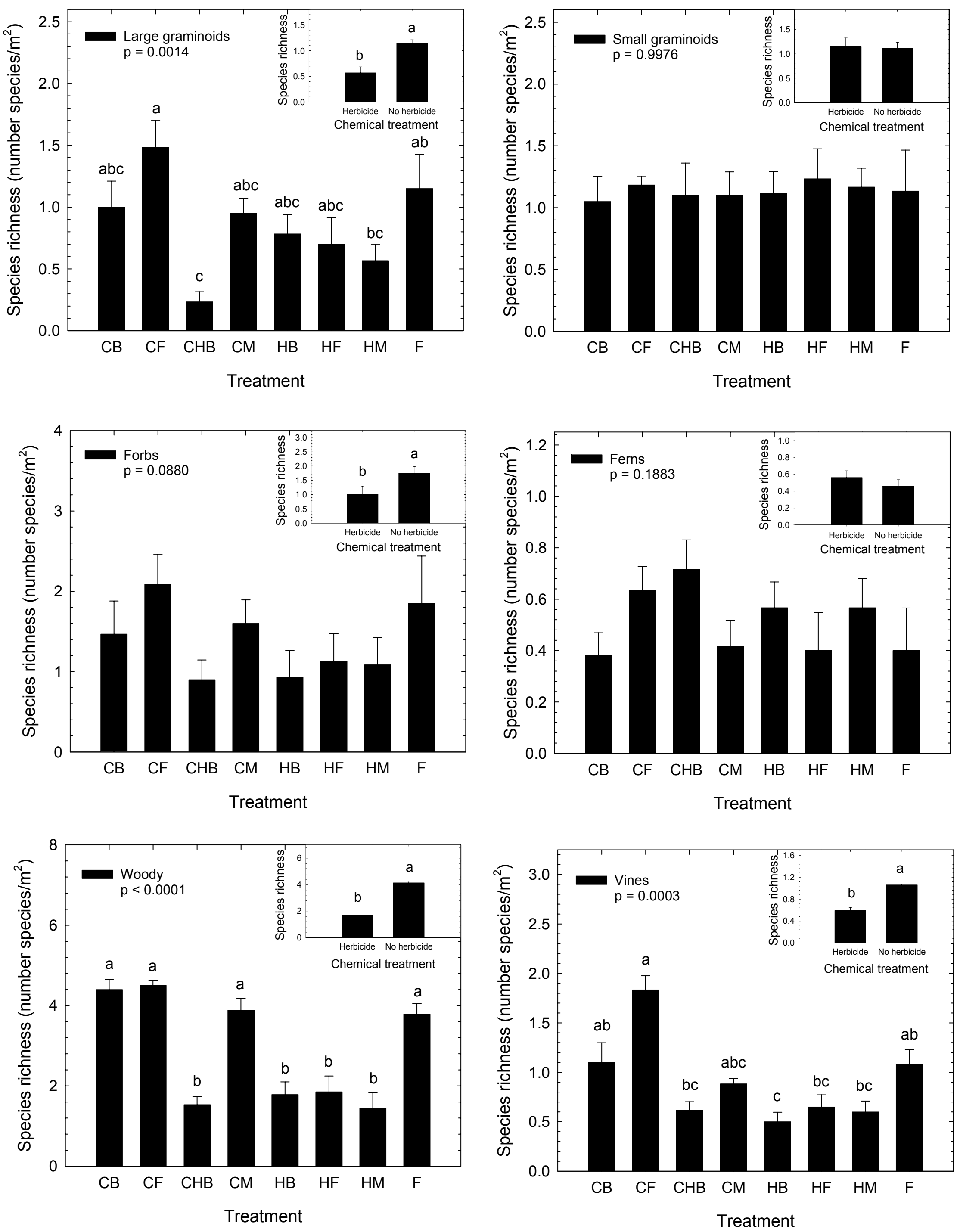

Figure 3.4.11. Species richness of ground layer vegetation for each functional group by treatment in 2004. Similar letters within a figure indicate no significant differences. Inset: Contrast of treatments with herbicide (CHB, HB, HF, HM) vs. treatments with no herbicide (CB, CF, CM, F).

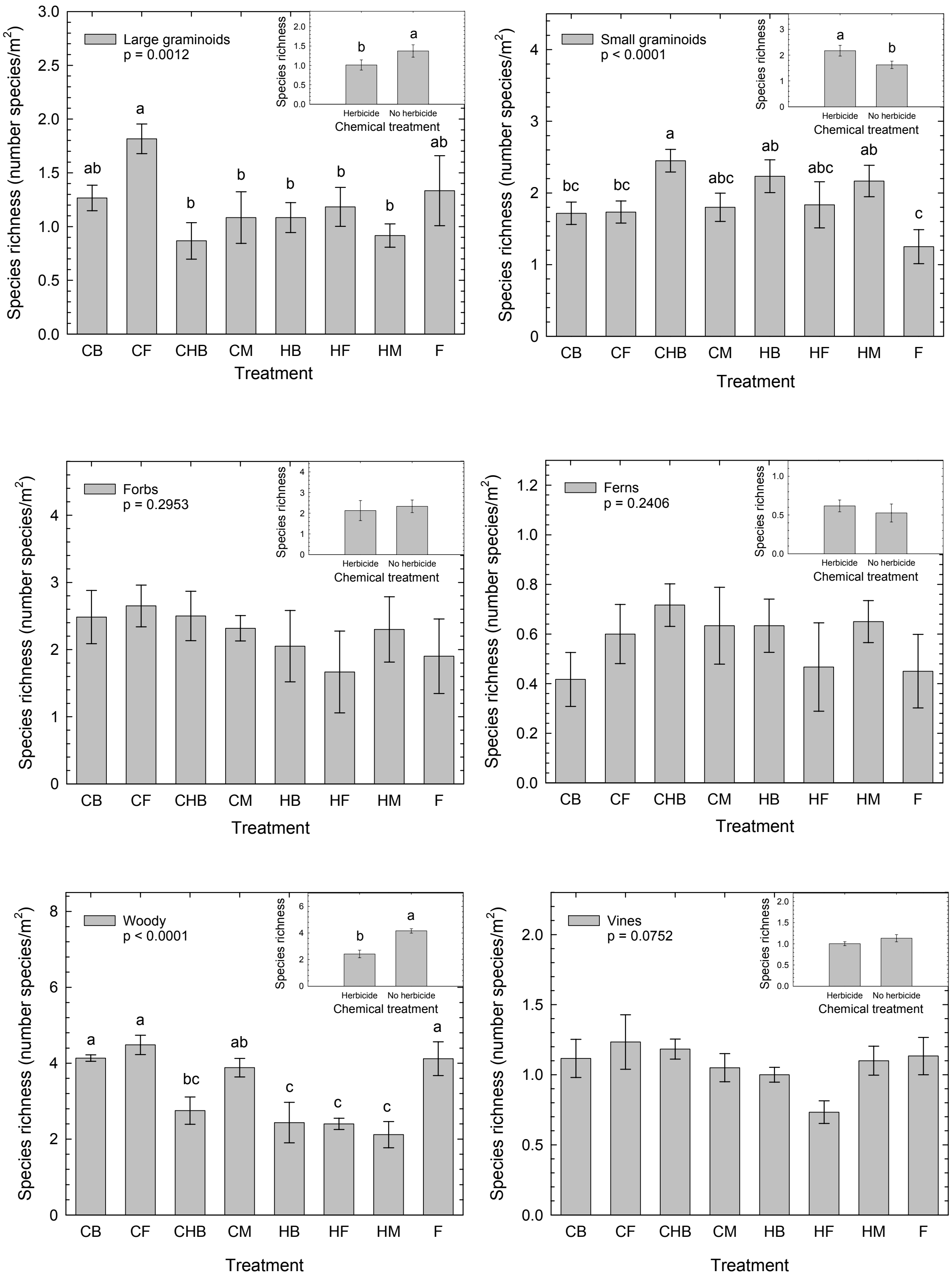

Figure 3.4.12. Species richness of ground layer vegetation for each functional group by treatment in 2005. Similar letters within a figure indicate no significant differences. Inset: Contrast of treatments with herbicide (CHB, HB, HF, HM) vs. treatments with no herbicide (CB, CF, CM, F).

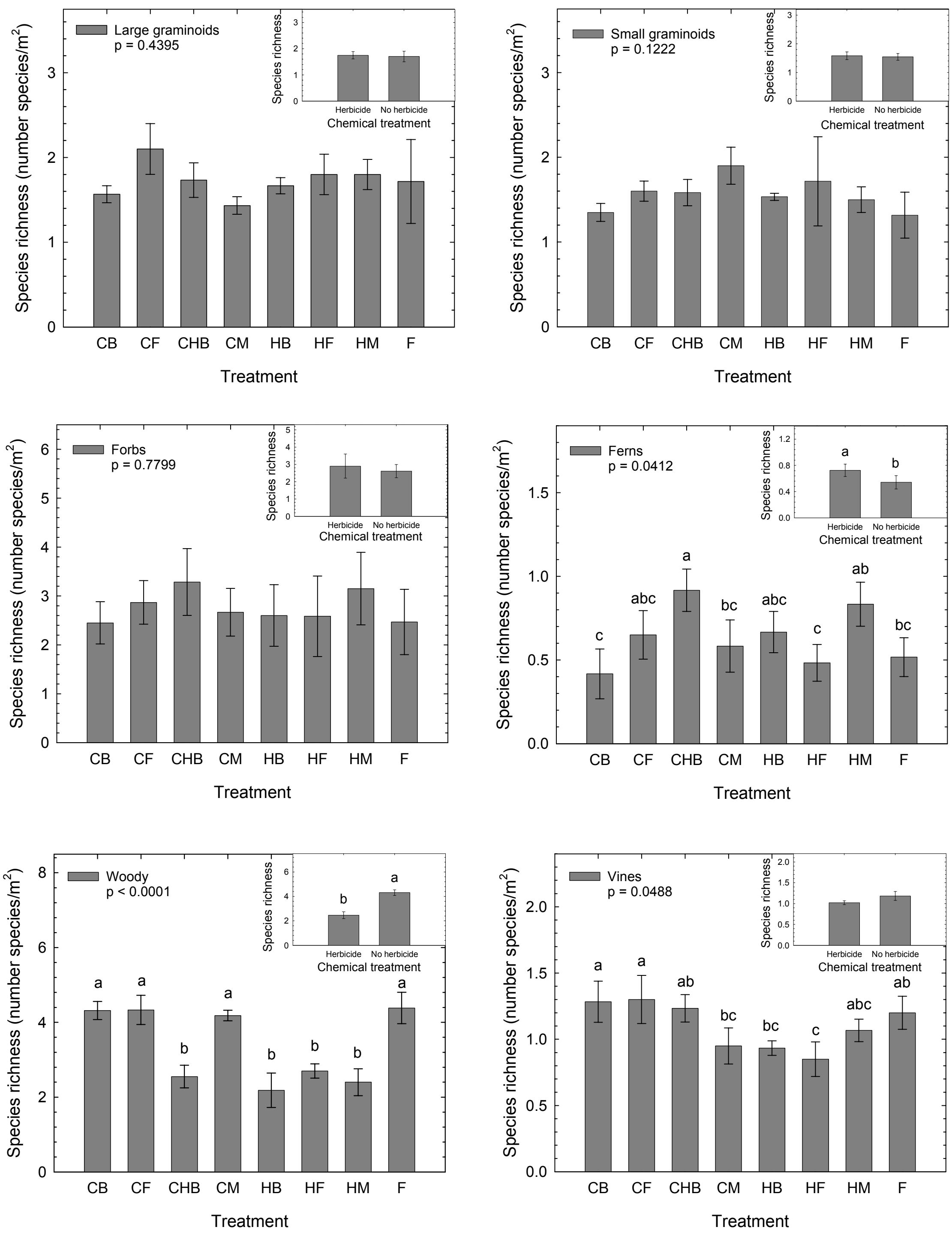

Figure 3.4.13. Species richness of ground layer vegetation for each functional group by treatment in 2006. Similar letters within a figure indicate no significant differences. Inset: Contrast of treatments with herbicide (CHB, HB, HF, HM) vs. treatments with no herbicide (CB, CF, CM, F).

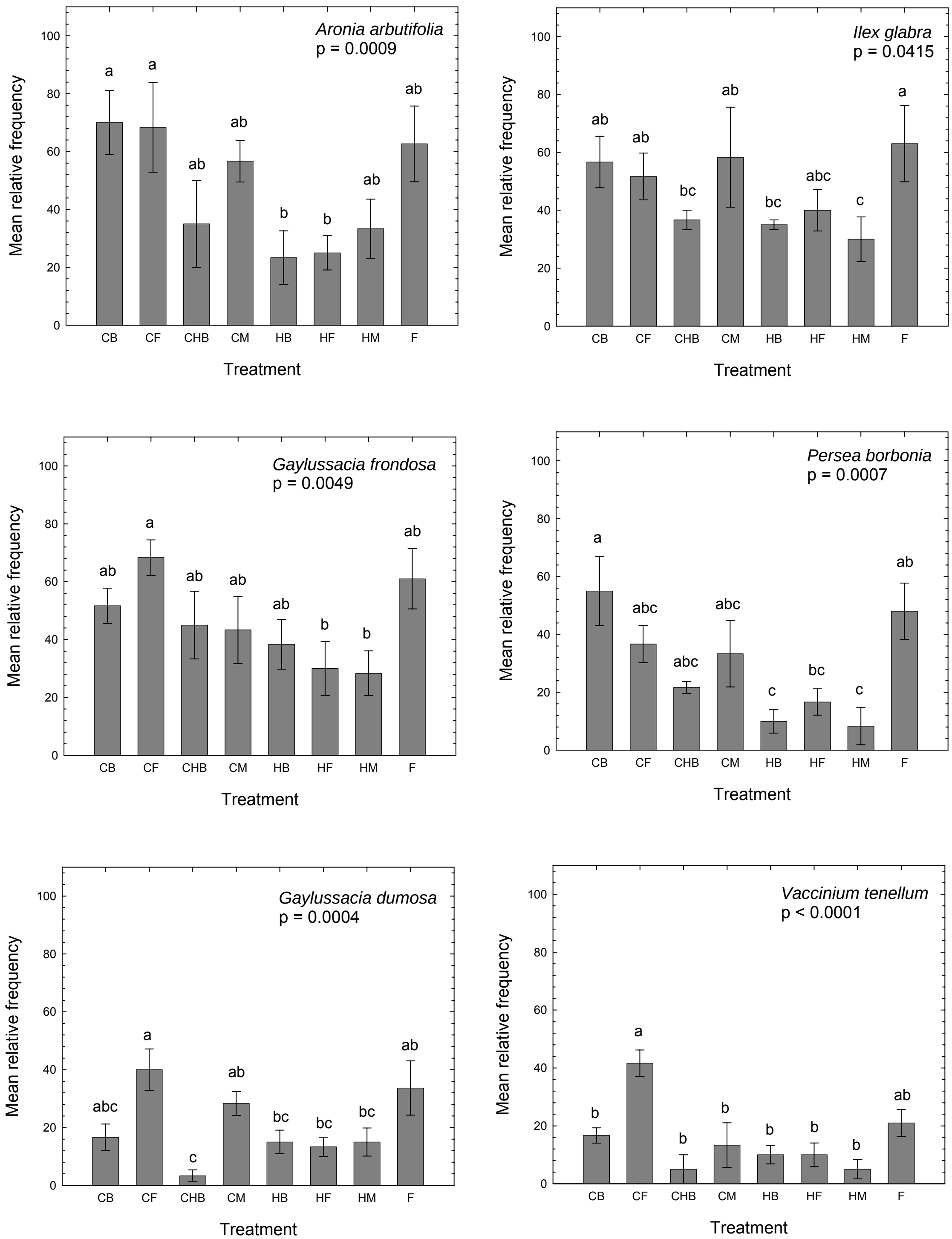

Figure 3.4.15. Mean relative frequency of common woody species by treatment in 2006. Similar letters indicate no significant differences. Mean relative frequency is the proportion of total quadrats sampled in which each species occurs at the plot level (n = 12).

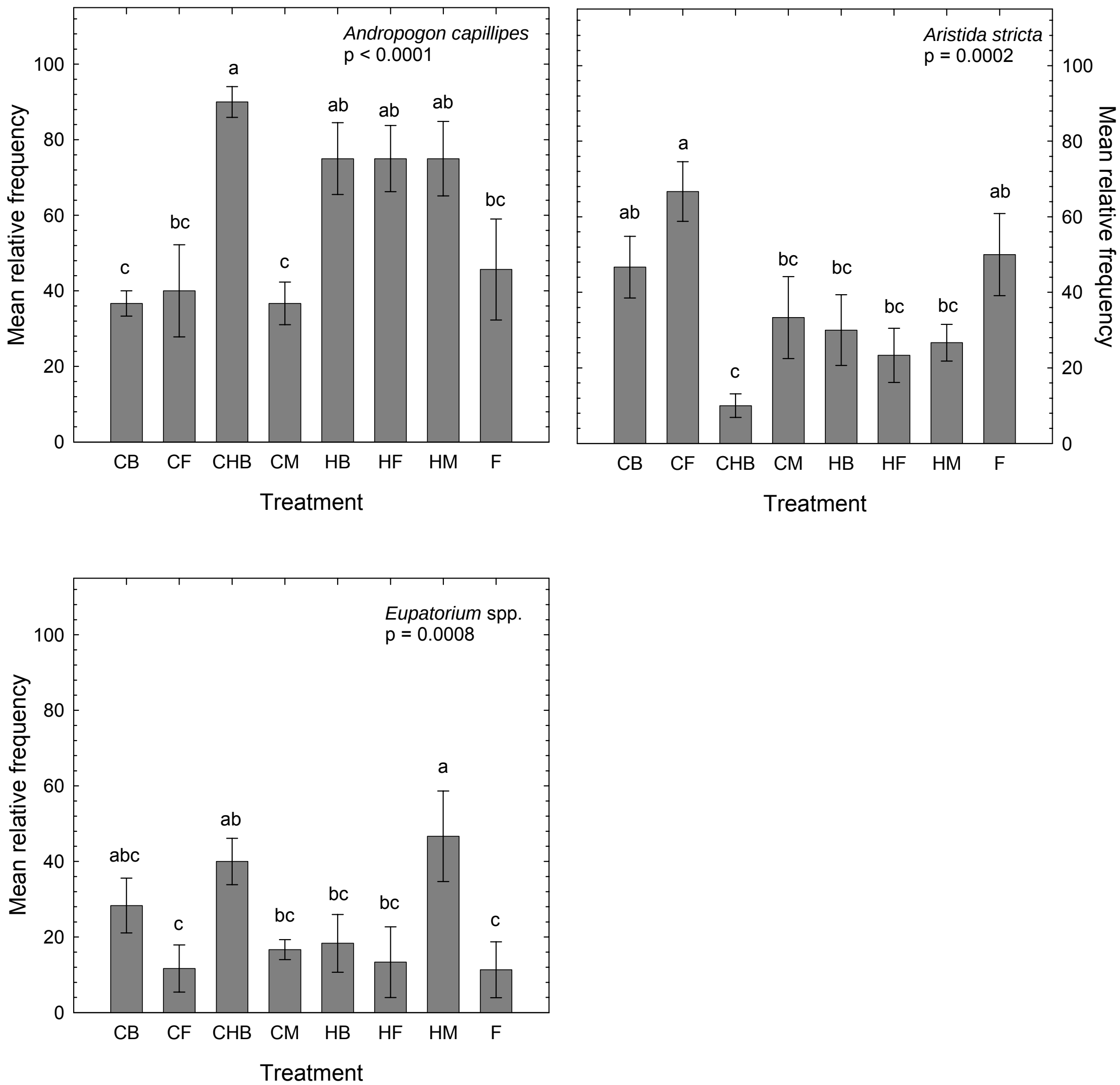

Figure 3.4.16. Mean relative frequency of common herbaceous species by treatment in 2006. Similar letters indicate no significant differences. Mean relative frequency is the proportion of total quadrats sampled in which each species occurs at the plot level (n = 12).

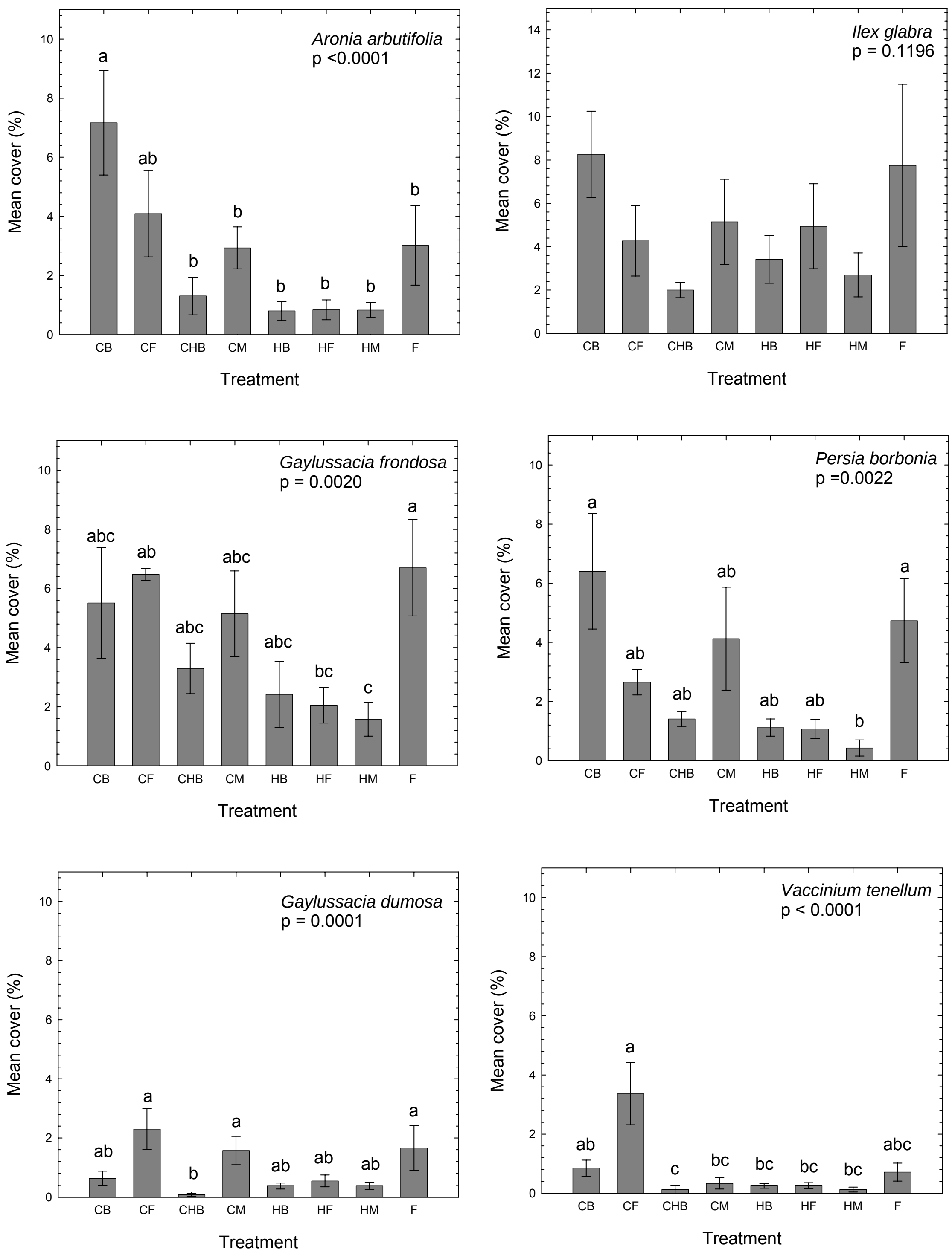

Figure 3.4.17. Mean percent cover of common woody species by treatment in 2006. Similar letters indicate no significant differences.

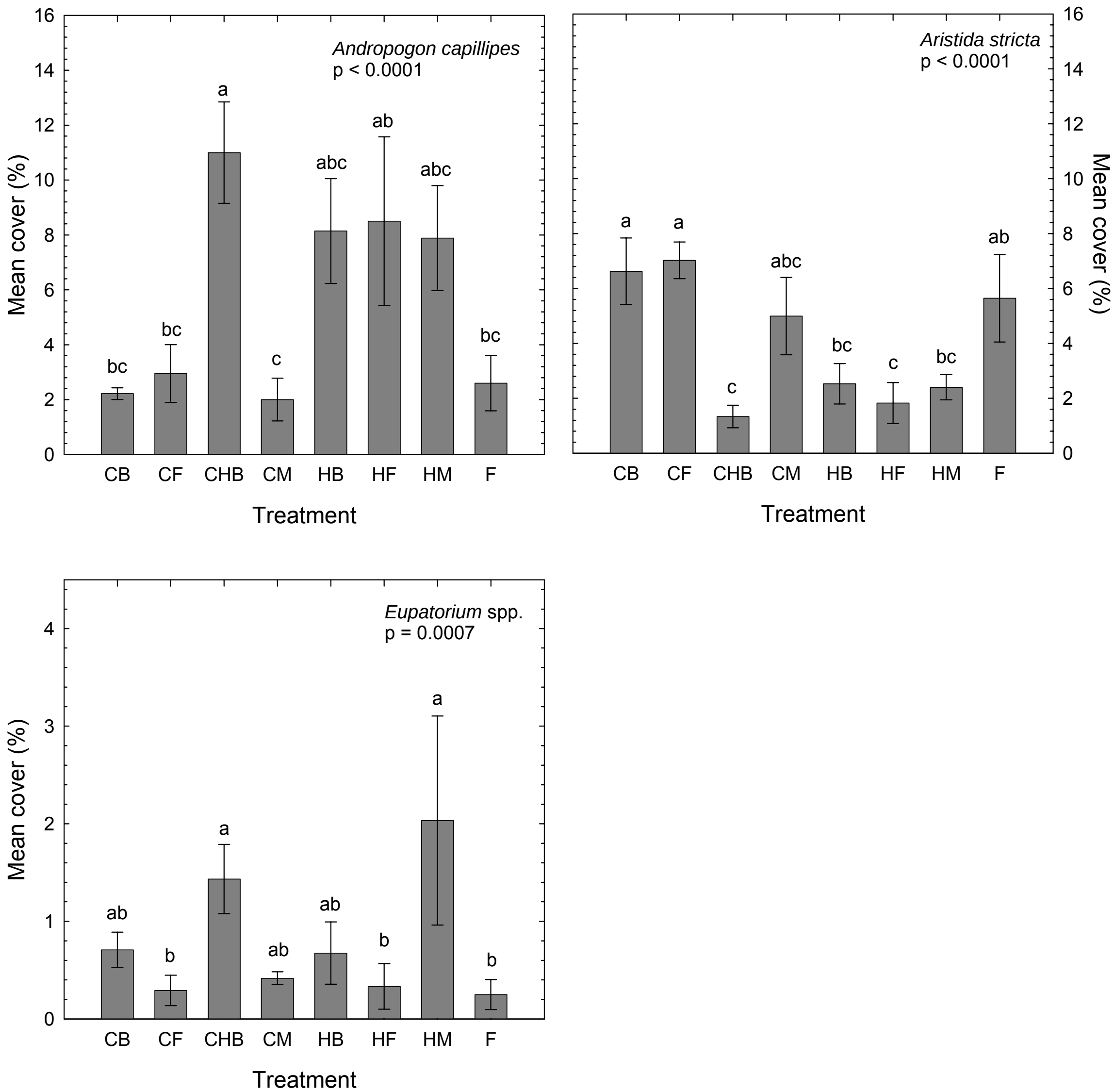

Figure 3.4.18. Mean percent cover of common woody species by treatment in 2006. Similar letters indicate no significant differences.

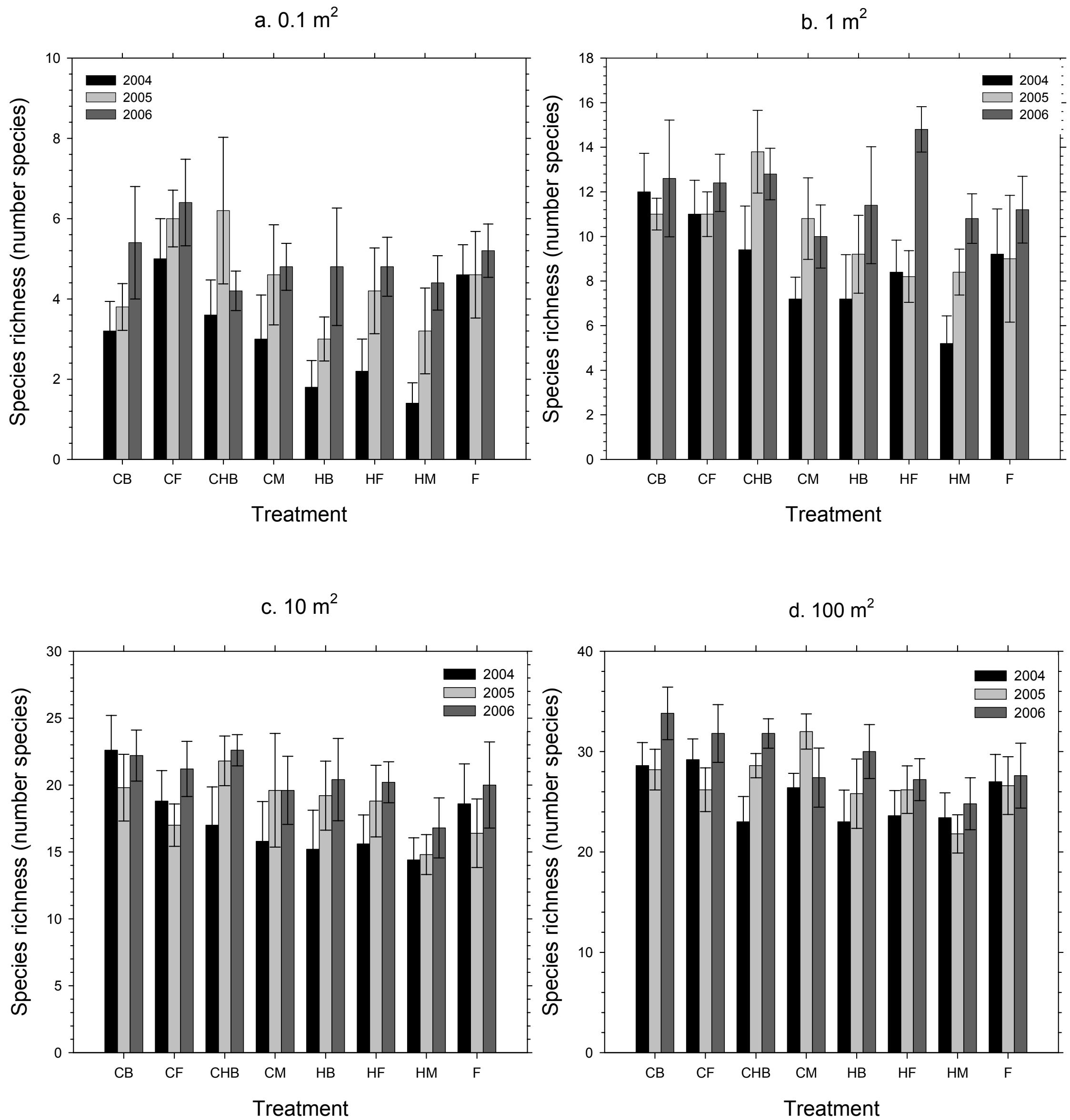

Figure 3.4.19. Species richness (number of species) at different sample scales in 2004, 2005, and 2006. Error bars represent one standard error.

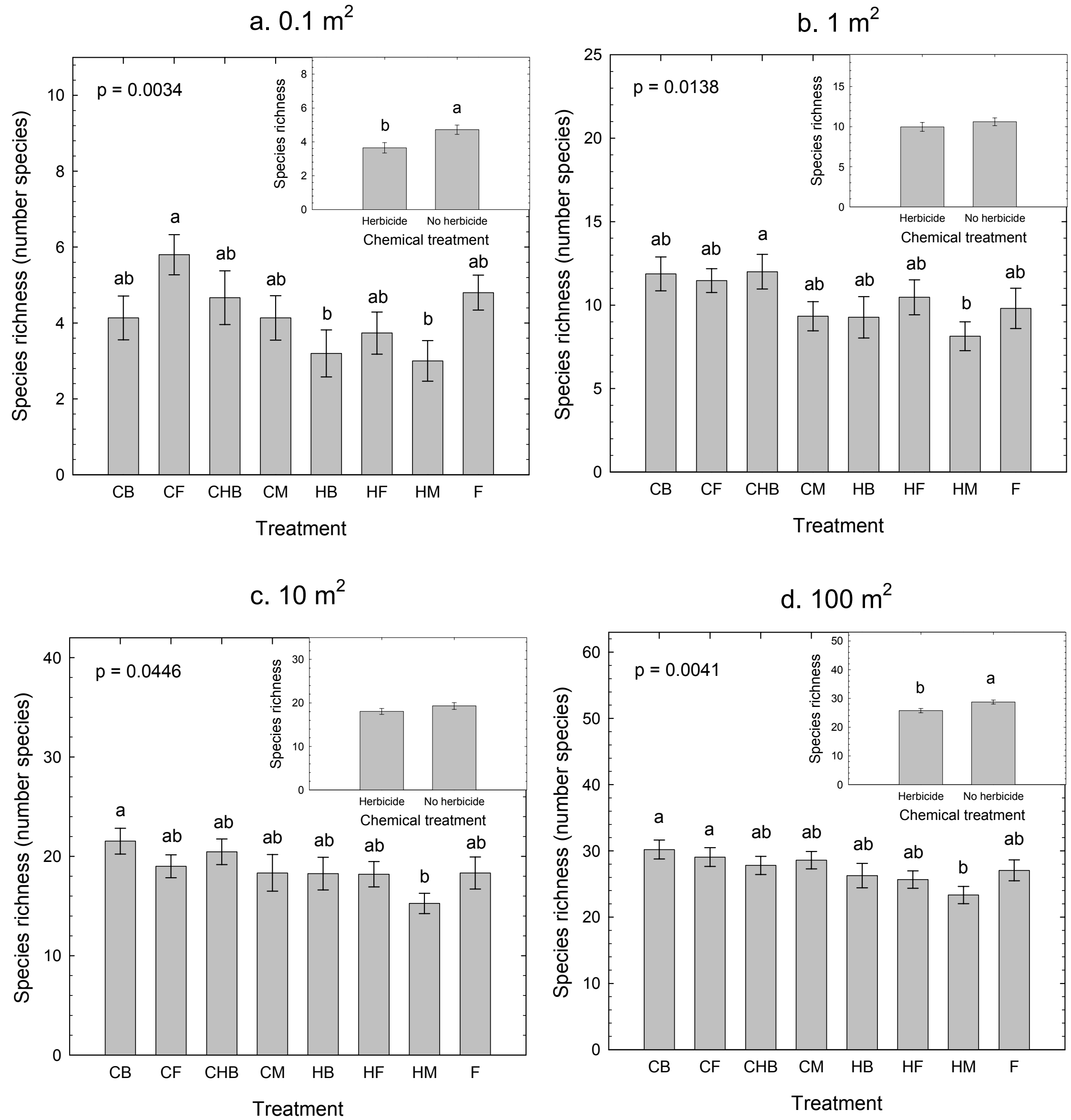

Figure 3.4.20. Species richness (number species) at different sampling scales across all years, showing treatment effects. Similar letters within a figure indicate no significant difference. Error bars represent one standard error.

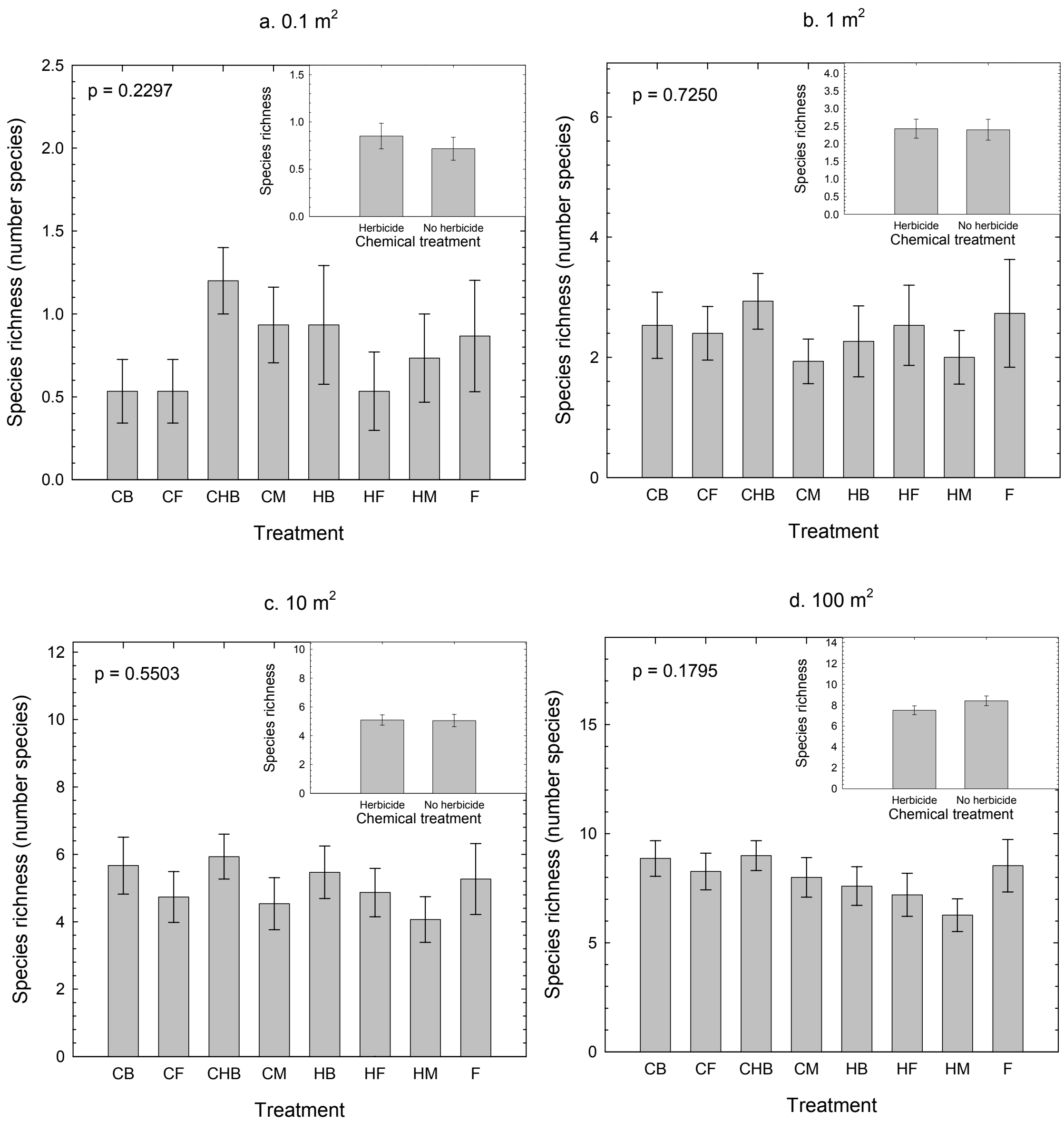

Figure 3.4.21. Species richness (number species) for forbs group at different sampling scales across all years, showing treatment effects. Error bars represent one standard error.

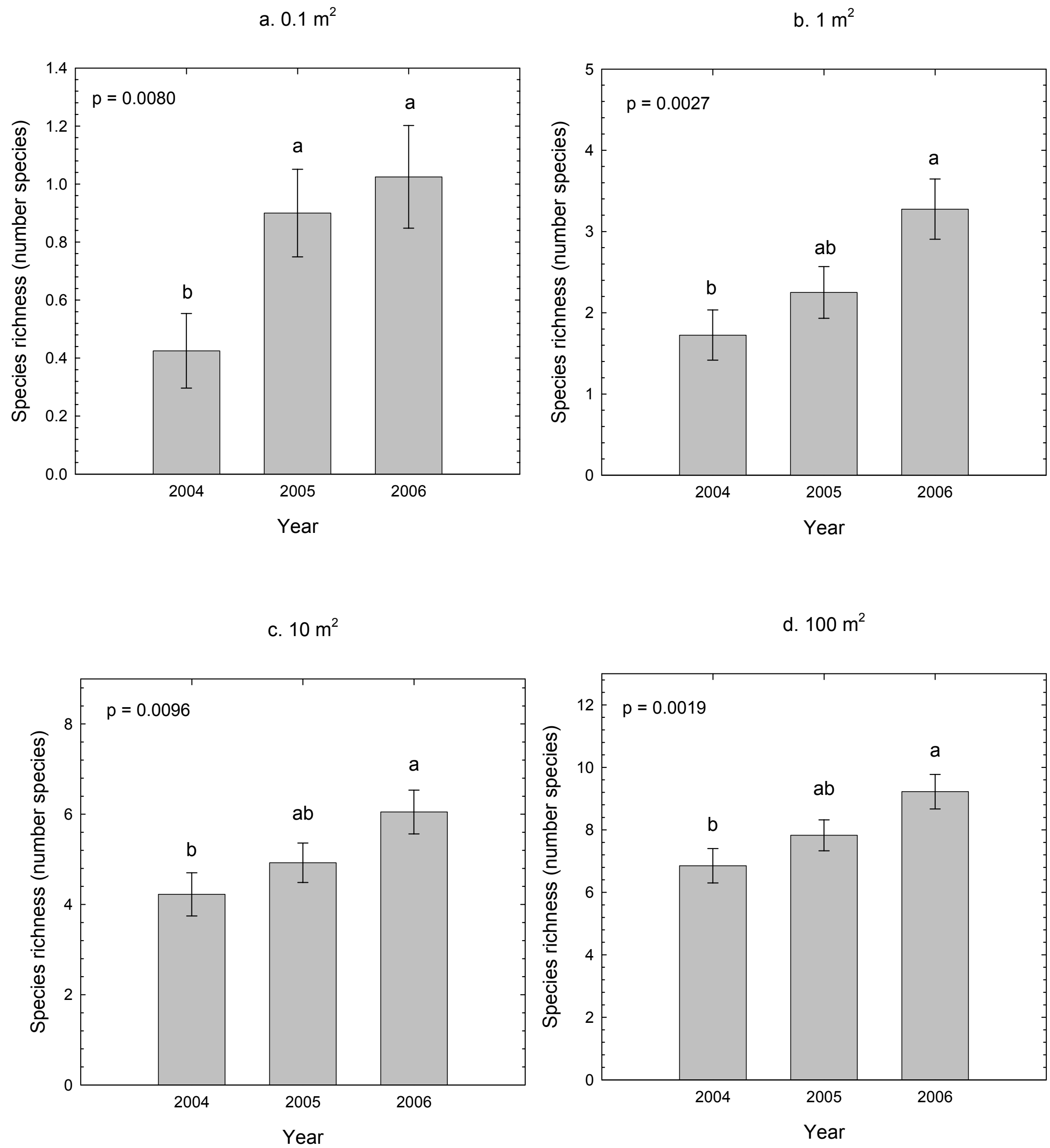

Figure 3.4.22. Species richness (number species) for forb group at different sampling scales across all treatments, showing year effects. Similar letters within a figure indicate no significant difference. Error bars represent one standard error.

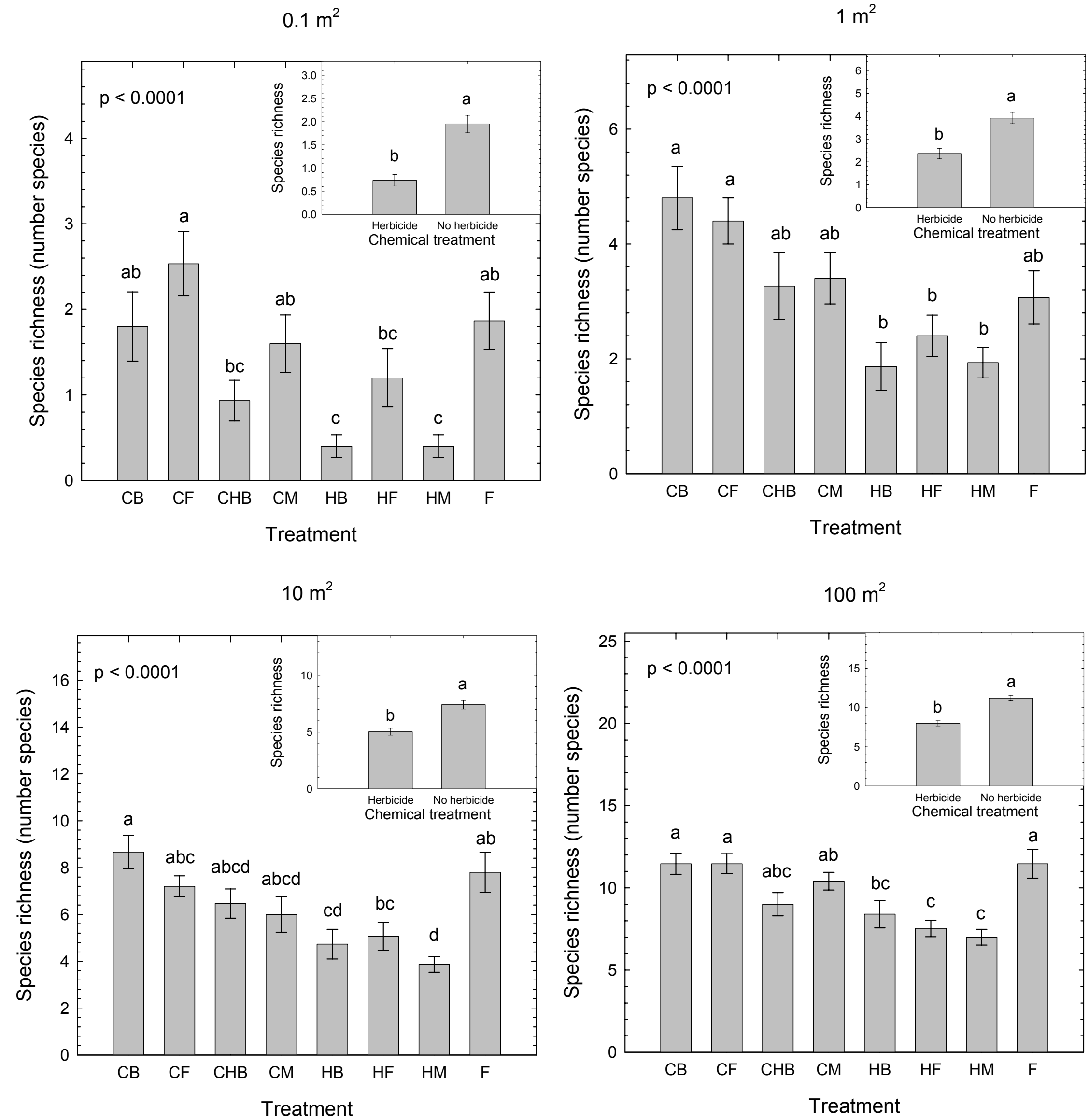

Figure 3.4.23. Species richness (number species) for woody species group at different sampling scales across all years, showing treatment effects. Similar letters within a figure indicate no significant difference. Error bars represent one standard error.

3.5 Site preparation treatments in wet coastal plain stands affect prescribed fire behavior in young plantations

This section addresses an objective that was added near the end of the project, that is, to determine if site preparation treatments affect prescribed fire behavior in the experimental plots. The results are informative, but inconclusive; some management concerns are identified.

3.5.1. Introduction

The purpose of site preparation treatments is to improve the survival and growth for planted seedlings. This usually is accomplished by either improving the resource availability or reducing competition. Experimental treatments in our study were designed to both control competition (by herbicide or chopping treatments) and to enhance planting conditions (by bedding or mounding). In this study we investigated the possibility that site preparation treatments may alter prescribed fire behavior. Prescribed burning is a management tool that is essential for maintaining the health of planted longleaf pine seedlings, and for maintaining diversity in the ground layer.

Fire behavior refers to a variety of fire characteristics including temperature, rate of spread, the location of the fire (ground-, surface-, or crown-fire), and total area burned. Several general factors affect fire behavior including fuel load, overall climate, rainfall and humidity, wind, and topography; site preparation effects would be related to the ways the operations affect fuel loads (Whelan 1995). Site preparation treatments and the resultant changes in vegetation influence fuel biomass, the size and arrange arrangement, and fuel chemistry (dictated by species composition), which are strong determinants of fire intensity. In addition, site preparation treatments that remove vegetation reduce fuel continuity, a factor that influences how fast fire moves across areas. Fire intensity (generally considered as how much heat energy is released) and rate of spread together determine important ecological effects, such as removal of biomass, reduction or removal of the forest floor, exposure of mineral soil, plant mortality, and increased flowering and seed. Changes in fuels such as those resulting from site preparation may alter what is left on the site in terms of dead fuel mass, live plants available for regrowth, and seed bed conditions that influence native species regeneration from seed.

In this analysis we tested for treatment effects on the following: (1) maximum temperatures recorded; (2) area burned, measured as percent burn cover in small sample units; (3) change in live fuel biomass, with separate analyses of herbaceous and woody (mostly shrubs) classes; (4) amount of fuel consumed, both changes in mass and changes relative to preburn levels; (5) amount of residual fuel.

3.5.2. Methods

All blocks were burned under similar weather conditions (Table 3.5.1) in March 2, 7, or 14, 2006. Only three blocks were available for sampling due to military training activities. Fires were ignited by drip torch using strip heads fires.

Sampling vegetation and dead and down fuels

Vegetation cover and fuel mass were assessed in December 2005 and within 2 weeks after burning (between March 15 and April 1, 2006). Although all blocks were burned, only three were available for sampling.

Vegetation and surface fuels were sampled along eight 10.67-m (35 ft) transects established in each treatment plot. The same transects were used for pre- and post-burn measurements. The corners of each treatment plot (approximately 283 x 179 ft.) were previously marked with metal conduit. Each plot was divided into quarters, yielding rectangular subplots approximately 141 x 90 ft. Subplot centers (approximate) were located at 84 ft from a plot on plot diagonals and marked with metal conduit to facilitate re-locating transects after burning. Subplot centers marked the origin of 2 transects per subplot. From each subplot center, two 35-ft (10.67 m) transects were established, each at a randomly determined azimuth (2 transects/subplot x 4 subplots/treatment plot x 8 treatments x 3 blocks = 192 transects; Figure 3.5.1).

We followed Brown's (1974) method for inventorying downed woody material along each transect before and after burning. One- and 10-hour timelag (0.64-2.54 cm diameter) fuels were sampled from 0-1.8 m, 100 h timelag fuels (2.54-7.62 cm) were measured from 0-3.0 m, and 1000 h timelag (>7.62 cm) fuels were tallied along the entire 10.7-m transect. The diameter, identification as either pine or other, and decay class (sound or partially decayed) were recorded for each 1000 h log.

Two 1 m x 1 m quadrats were randomly located along each transect (16 quadrats/plot). In cases where random positions resulted in overlapping sample units, the second quadrat was placed immediately adjacent to the previous quadrat. In each quadrat woody cover and herbaceous cover were recorded by cover classes (trace-1%, 2-5%, 6-10%, 11 -25%, 26-50%, 51-75%, 76-95%, 96-100%); data were converted to the mid-point of the cover class for analysis. Litter depth (cm) to mineral soil was measured at the center of each vegetation measurement quadrat. Litter was defined as the loose layer of twigs, dead grasses and forbs, fallen leaves and needles that were readily identifiable and not altered by decay. There was no measurable duff accumulation, probably a result of a recent history of short interval prescribed burning. Finally, from a randomly selected quadrat in each subplot, all above ground vegetation was harvested by clipping at the ground level, categorized as either woody or herbaceous in habit, and placed in paper bags for weighing. In the lab vegetation samples were dried at 70 C for 48 hours and weighed.

Fire temperatures

To better understand fire behavior, we deployed pyrometers consisting of array of 10 aluminum tags each painted with a different temperature-sensitive paint (Omega Engineering, Inc.) with a known response temperature. Paint temperatures used were 250, 300, 450, 500, 600, 700, 800, 900, 1000, and 1200°F (121, 149, 232, 260, 315, 371, 427, 482, 538, 649°C). Arrays were suspended at about 5 cm which corresponds to the approximate

height of the longleaf pine seedlings in these plots. Such pyrometers provide an indication of the maximum temperature achieved by the passing of the flaming front, but no measure of duration. When pyrometers showed no change from ambient, the ambient morning temperature (40° F) was assigned. Twenty-five pyrometers were placed in each treatment plot, one with each unclipped live vegetation sampling quadrat (12), and the remaining 13 spaced at 4 m intervals and positioned to form an “X” crossing in the middle of the plot. A total of 600 pyrometers (25 x 8 treatments x 3 blocks) were installed. In this report the data generated from paint tag pyrometers is referred to as the pyrometer data.

Previous studies suggest that pyrometers similar to ours indicate temperatures often differ from those recorded by nearby thermocouples (Iverson et al., 2004; Kennard et al., 2005; Wally et al. 2006). To test this and to assess the relationships between pyrometers and directly measured temperatures, we installed thermocouples (Type K) connected with HOBO® dataloggers (Onset Computer Corporation, Pocassett, MA 02559) to record temperatures adjacent to pyrometers in the CF, CB, HF, HB treatment plots in 2 blocks (25 thermocouples x 4 treatment plots x 2 blocks = 200 thermocouples deployed). Prior to the burn, thermocouples were positioned at a height of 5 cm and wires to the dataloggers were buried. Calibrated dataloggers were set to record temperature every 3s, and started shortly before ignition. Temperature readings from thermocouples comprise the thermocouple data set.

Data analysis

The relationship between pyrometer and thermocouple data was examined with Spearman rank correlations.

To analyze the pyrometer data (8 treatments, 3 blocks), we used Friedman’s test (SAS, Proc FREQ; cmh test statistic) to test for treatment effects on maximum temperature (TEMP) and on burn cover (PCTBURN). Where a significant effect was indicated, we examined the medians and 95% confidence intervals (Mood’s Median test; MINITAB). When 95% confidence intervals did not overlap, we concluded a significant difference between treatments.

Linear regression methods were used to quantify the relationships between aboveground biomass and vegetation cover; separate analyses were conducted for herbaceous and woody vegetation. Regression analyses produced the following relationships between vegetation cover and biomass:

$$\log(HWT) = 1.6857 + 0.0084 * HPCT \quad (r^2 = 0.591;\ p < .0.0001)$$

$$\log(SWT) = 1.2551 + 0.0239 * SPCT \quad (r^2 = .5109;\ p < 0.0001)$$

where HWT= herbaceous biomass (g), HPCT= herbaceous cover (%), SWT= shrubby biomass (g), SPCT= shrubby cover (%).

Variables of interest were change in herbaceous biomass (HDIF= biomass $_{preburn}$ – biomass $_{postburn}$; g/m^2), change in shrubby biomass (SDIF), change in total biomass (TOTDIF), and the total change as a proportion of total initial biomass (RELDIF). Plot

means were calculated and used in analyses of variance to test for treatment effects. Because we found live vegetation consumption to be dependent on pre-fire biomass, we tested for treatment effects on HDIF and SDIF using a mixed model analysis of variance with treatment as a fixed variable and pretreatment herbaceous or shrubby biomass as random variables. For other tests we used one-way analyses of variance with treatment as a fixed effect (Proc Mixed; SAS 2003). Assumptions of normality and equal variances were tested with Shapiro-Wilk normality tests and by examining normal probability plots.

The biomass of dead and down woody fuels was calculated using published equations (Brown 1974; Forest Products Laboratory 1999) and litter was converted to biomass using published bulk density values (Brown 1974). Response variables of interest were the difference between pre-burn and post-burn litter mass (LITDIF), 1 hr (DIF1), 10 h (DIF10), 100 h (DIF100), 1000 h timelag fuel mass (DIF1000), and total woody fuel mass (TOTDIF). Because total fuel consumption was possibly limited by pre-burn fuel loads, we also examined fuel consumption as a proportion of pre-burn fuel loads (RELDIF). We used Friedman's tests to test for treatment effects on dead fuel components. When a significant treatment effect was indicated, we used a Moods' median test which produced estimates of treatment medians with 95% confidence intervals (MINITAB). We compared treatment medians, and concluded that the treatment differences were significant if 95% confidence intervals (CI) did not overlap.

3.5.3. Results

Maximum temperatures

Thermocouple temperatures were significantly ($p<0.001$) correlated with pyrometer data (Spearman rank correlations; rho = 0.381). Based on this relationship, we were confident that using the pyrometer data for additional analyses would provide general patterns of temperature distributions within plots.

The distribution of maximum temperatures derived from all pyrometers is shown in Figure 3.5.2. The most frequent temperature recorded in all treatments was the ambient temperature on the day of the burn (40° F), which was assigned to pyrometers in which the fire temperature did not reach the lowest temperature indicator paint, but the next most frequently observed reading was the highest of the indicator paints (1200 ° F). The flat planted treatments had the fewest tags assigned the ambient air temperature (10.7, 34.7, and 37.3% for CF, HF, and F, respectively) and were among the highest in percentage maximum temperatures (40 and 32% for the F and CF plots). The CHB treatment showed both the highest percentage of ambient temperature tags (70.6%) and fewest maximum readings (4.0%). The CB plots had the second most ambient temperature readings (58.7%), and the HB and CB plots were the only other treatments with fewer than 10% in the 1200 ° F class. Mounded treatments (CM and HM) tended to be intermediate with respect to high temperatures. The analysis of pyrometer data indicated a significant treatment effect on maximum temperature ($p<.001$; df = 7, sample size = 599). A comparison of median 95% confidence intervals showed that the median of the CHB treatment (40°F) was lower than the CF, F, and HF treatments (800, 900, and

500°F respectively). CB, HB and HM medians were significantly different (lower) than the CF and HF; they were also lower than the F treatment, but not significantly so. Only the CF plots had fewer than 25% of the measurements that fell below about 400 °F (Figure 3.5.3); in all other treatments the 25th percentile included 40 °F.

Percent burned in small quadrats

The Friedman's test on percent burn indicated a significant (alpha level = 0.1) treatment effect (p=.0756, df=7, sample size = 288), but there were few significant differences among treatments. The HB estimated 95% CI of the median did not overlap with the lowest HM and CHB treatments. There are no clear patterns in the data distributions (Figures 3.5.4, 3.5.5).

Live biomass

Live biomass data are summarized in Table 3.5.2. The ANOVA model for change in herbaceous biomass (HDIF) that included preburn herbaceous biomass and treatment was significant [model: df=$_{8,\ 15}$; F=3107; p<0.0001]; however, the treatment effect was not (df=7, F=1.12, p=0.398). Results for the change in shrubby biomass were similar [model: df= $_{8,\ 15}$; F=3.08, p=.0288], with a significant effect of preburn biomass but no treatment effect (df=7, F=1.37, p=.2851). Treatment effects on relative change in herbaceous and shrubby biomass were not significant, ($F_{7,16}$; p=.7610 and p=.4194 respectively).

Dead and down fuels

Descriptive statistics for mass of woody fuels by fuel class are summarized in Table 3.5.3. Data were not normally distributed and attempts to transform data to meet assumptions for parametric analyses failed. Based on Friedman's test, there were marginally significant (alpha = .10) treatment effects only indicated for DIFLIT, TOTDIF, and RELDIF (p=.0774, .0813, and .0866 respectively). Although a median test for treatment differences, which cannot control for block effects, was significant only for RELDIFF (df=7, χ^2=13.33, p=.078), it was possible to examine median CIs and data distributions to note variations in data distributions among treatments. The median change in litter mass was greatest in the CF treatment and lowest in CB (Figure 3.5.6); additionally, the CB litter mass changes were uniformly low. Although the range of litter change in CF was intermediate, a comparison of CIs showed the CF median to be greater than in all treatments except HF. The greatest median change in total fuel mass (TOTDIF) was found in the CF treatment and it was greater than CB, CHB, F, HB, and HM (Figure 3.5.7). The CM treatment showed the widest range of variation, up to a change of 14 tons/acre, with extreme outliers, contrasting with uniformly small fuel mass changes in the CHB and F, the most and least intensive experimental treatments, respectively. The changes in fuel mass as a percentage of preburn levels (RELDIF) had similar total ranges across treatments, with extreme outliers for all treatments except HB greater than 0.75 (Figure 3.5.8). Based on non-overlapping 95% CIs, the medians of both CM and HF treatments differed from CH and CHB medians, which were essentially zero.

There was a significant treatment effect on the sum of 1-, 10- and 100-hr fuel classes remaining after the prescribed fire (Friedman's test; p = 0.056; n=95). (Thousand-hour fuels were excluded from this analysis because fuel reduction in this class was essentially zero.) The Mood's median test was also significant (p=.008) and a comparison of 95% CIs showed that HB and HM treatment medians were greater than for the F treatment. The median value in HB was also greater than the HF median. The F and HF treatments had both low amounts of fuel remaining and a narrow range of variation compared to other treatments (Figure 3.5.9). In combination with herbicides bedding or mounding resulted in higher residual fuel loads than in flat treatments.

3.5.4. Discussion

Among treatments, the CF treatment stands out with the fewest lowest temperature readings and the largest reductions in litter and total dead biomass. Based on the analysis of ground layer vegetation (**Section 3.5**), the CF plots had among the highest cover, much of which was consumed by the fire. The amount of fuel consumed is generally positively related to fire intensity (heat released; Whelan 1995), and in the case of the CF plots, the removal of live and dead biomass is consistent with the high frequency of 1200 °F tag readings. Chopping during site preparation generally redistributes woody fuels spreading them uniformly and low to the ground, and reduces the sizes of woody fuels, thereby creating favorable conditions for burning (Johnson & Gjerstad 2006). Thaxton and Platt (2006) reported higher maximum temperatures and more complete fuel consumption in patches with experimental additions of woody fuel in longleaf pine savannas. These conditions were further associated with reduced shrub vigor and re-sprouting after burning. The fuel bed created by chopping may similarly have facilitated fuel consumption in our plots. In the flat-planted plots the shrubs were upright and larger, and in the herbicide plots dead shrubs remained standing, both conditions likely to reduce woody fuel consumption.

We hypothesized that bedding and mounding would interfere with fire spread and patterns in the distribution of fire temperatures in this study support this hypothesis. Bedded plots had more unburned or cool spots than flat plots, with mounded treatments intermediate. The continuous beds both removed long patches of surface vegetation (potential fuels), and created wet troughs along the beds. Increased fuel moisture would reduce fire temperatures by reducing fuel consumption, but may even prevent fire spread across such areas. Mounded treatments produced patches without fuel and wet pits, but these conditions were not continuous and likely facilitated more uniform fire spread. Differences in percent area burned were expected, however, the average percent of small sample plots burned may not have been the best way to measure the proportion of the total plot burned. Many point samples distributed randomly or stratified along transects are likely to yield more meaningful results.

While the significant effect of pretreatment live biomass on the amount of biomass consumed is not surprising, we were surprised by the lack of treatment differences. Fires in all the plots were somewhat patchy, leaving patches unburned. If burning fires had

been conducted under different conditions that increased fire behavior (e.g., longer fuel lengths), differences may have been detected.

We suspect that burning more aggressively under different conditions could overcome the differences resulting mainly from bedding and mounding. If the apparent interference in fire spread persists changes in vegetation structure would be expected. Shrubs would be expected to proliferate, likely in the ditches off the beds where fire is impeded and competition with the planted pines is reduced. This pattern is readily observed in existing flatwoods plantations on Camp Lejeune. Increased woody plant production in flatwoods accompanies decreased herbaceous cover, an undesirable outcomes from the perspective of ecosystem function, biodiversity, and red-cockaded woodpecker habitat quality (USDI FWS 2004).

3.5.5. Conclusion

Bedding is likely to reduce fire spread and potentially fire intensity in young pine plantations. Altered fire behavior may lead to changes in increasing woody cover and reduced herbaceous cover in the ground layer vegetation. It may be possible to mitigate potential effects of beds on fire behavior by choosing burning conditions that achieve the desired fire effects. Chopping appears to facilitate prescribed fire, most likely by severing or breaking the tops of shrubs and distributing that woody fuel into a well-aerated fuel bed. Though chopping may not provide effective competition control for early seedling growth (Section 3.4), it may lead to increased fire temperatures and fuel consumption, potentially benefiting woody shrub dominance in the ground layer.

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Tables and Figures

Table 3.5.1. Weather on burn days. Data were drawn from the fire planning forecasts acquired from the National Weather Service on the web at fire.boi.noaa.gov website, accessed on the morning of the burn.

Max Temp (ºF)	Max Temp (ºC)	Min Temp (ºF)	Min Temp (ºC)	Wind direction	Wind speed, early (mph)	Wind speed, late (mph)	Minimum R.H. (%)
77	25	39	3.9	SW	12	20	32
53	11.7	29	-1.7	N	15	18	36
71	21.7	38	3.3	SW	13	11	37

Table 3.5.2. Live vegetation biomass (T/acre) summarized by treatment. Means and standard errors (n=3 blocks).

	Herbaceous Biomass (g/m^2)				Woody Biomass (g/m^2)				Herbaceous change		Woody change		Herbaceous relative change		Woody relative change	
	Pre-burn		Post-burn		Pre-burn		Post-burn		HDIFF		SDIFF		HRELDIF		SRELDIF	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
CB	157.583	6.828	54.061	0.229	122.350	41.471	130.420	98.098	103.521	7.057	-8.070	84.579	0.568	0.015	-1.217	1.320
CF	178.499	37.481	53.722	0.025	182.303	29.375	22.285	0.754	124.777	37.456	160.018	29.215	0.623	0.092	0.620	0.036
CH	180.121	11.528	54.207	0.243	42.181	7.624	247.793	140.421	125.914	11.290	-205.611	132.940	0.632	0.021	-8.934	5.101
CM	173.959	11.042	53.826	0.127	265.935	101.876	75.679	43.436	120.133	11.096	190.256	122.234	0.583	0.032	0.288	0.270
F	181.834	29.915	54.166	0.326	541.700	299.418	136.876	50.718	127.668	30.222	404.824	349.444	0.558	0.089	-1.762	1.913
HB	193.266	10.612	53.693	0.014	202.223	60.249	234.569	112.577	139.573	10.616	-32.346	52.576	0.664	0.025	-6.517	3.936
HF	173.547	18.530	53.812	0.112	174.900	81.689	114.005	65.397	119.736	18.419	60.895	122.976	0.605	0.034	-3.919	3.124
HM	207.877	20.271	53.812	0.112	177.494	52.257	161.152	123.063	154.065	20.159	16.342	97.062	0.648	0.010	-5.238	5.394

Table 3.5.3. Differences between pre-burn and post-burn biomass (T/acre) by fuel class and total fuel biomass, and relative change in total fuel biomass (total difference/pre-burn total). Means (n=3) and standard errors shown.

Class	1-hour		10-hour		100-hour		1000-hour		Litter (LITDIF)		Total fuels (TOTDIF)		TOTDIF / pre-burn Total	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
CB	0.013	0.005	0.333	0.096	0.366	0.264	0.000	0.000	0.066	0.050	0.776	0.066	0.197	0.316
CF	0.065	0.037	0.351	0.133	0.658	0.380	1.143	0.576	0.471	0.048	2.688	0.092	0.235	0.346
CH	0.001	0.001	0.018	0.018	0.073	0.073	0.000	0.000	0.219	0.067	0.279	0.061	0.093	0.075
CM	0.052	0.023	0.222	0.055	0.439	0.439	1.917	1.917	0.175	0.039	2.804	0.027	0.313	1.724
F	0.044	0.008	0.166	0.055	0.000	0.000	0.000	0.000	0.142	0.061	0.353	0.081	0.302	0.098
HB	0.013	0.013	0.074	0.049	0.439	0.335	0.313	0.444	0.274	0.048	1.112	0.029	0.063	0.419
HF	0.064	0.033	0.370	0.188	0.219	0.127	0.799	0.799	0.230	0.099	1.681	0.041	0.287	0.951
HM	0.023	0.019	0.166	0.166	0.219	0.127	0.260	0.260	0.318	0.044	0.987	0.090	0.223	0.326

*

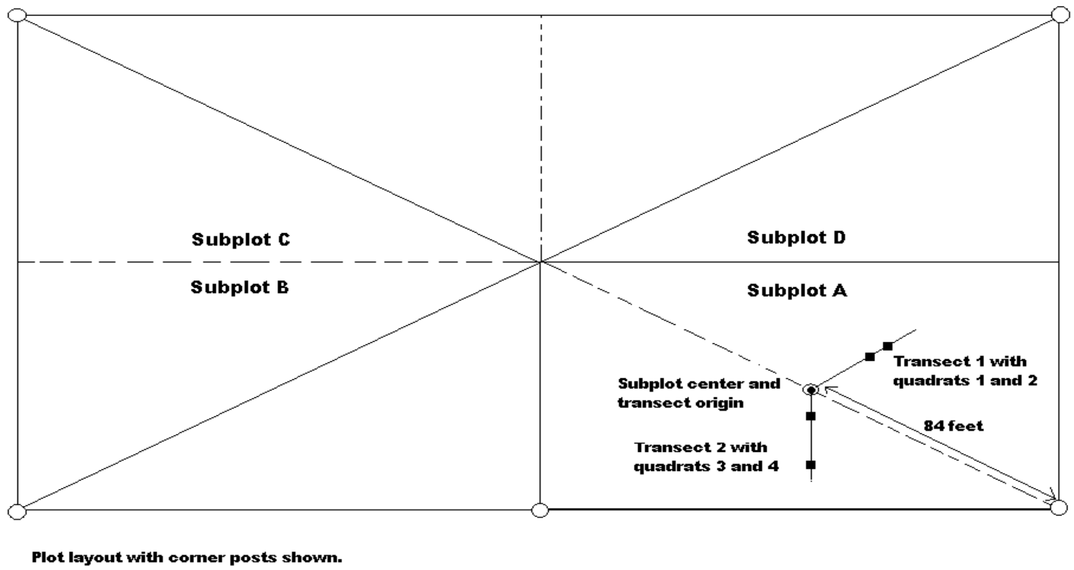

Figure 3.5.1. Plot layout for fuel sampling transects.

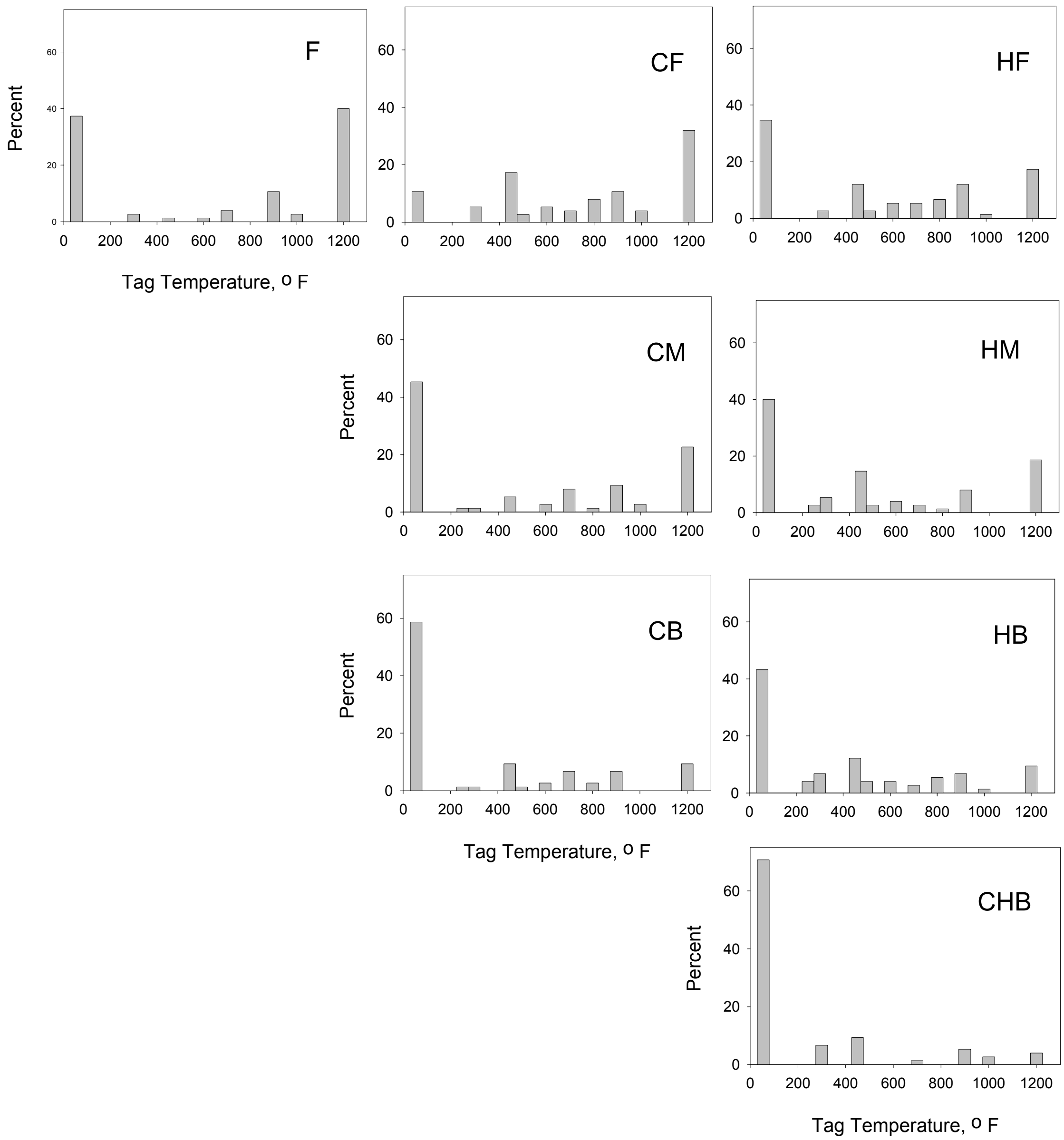

Figure 3.5.2. Frequency distribution of tag temperatures by treatment. The total number of tags per treatment was 75, except 74 in the HB treatment.

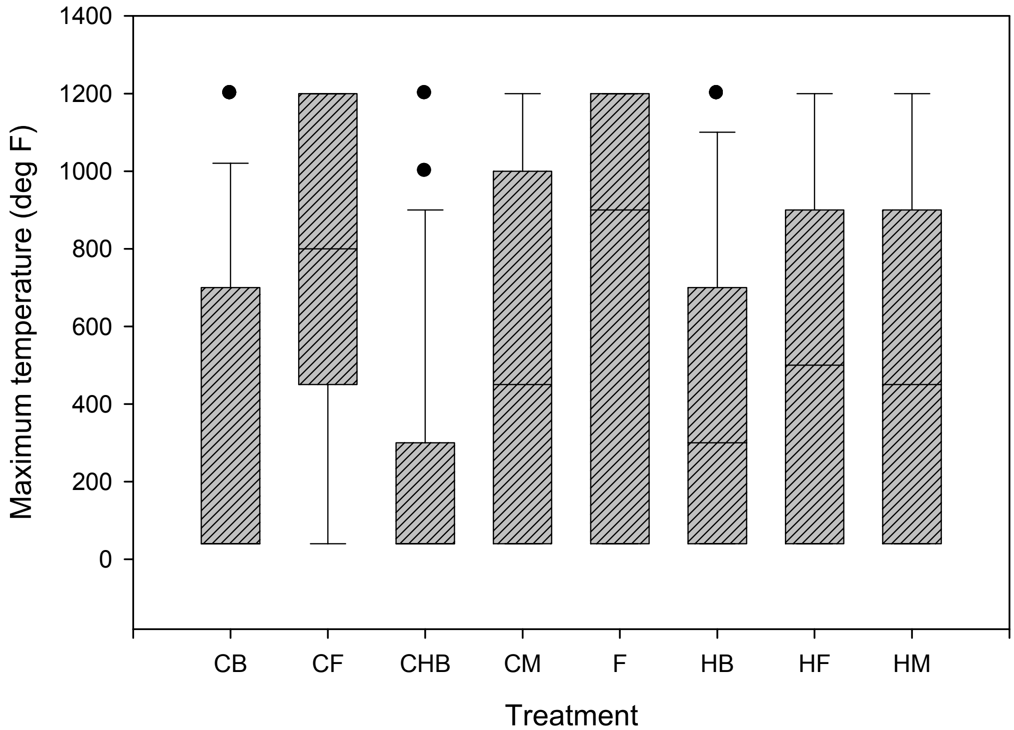

Figure 3.5.3. Maximum temperature data determined from paint pyrometers by treatment. The boundary of the box closest to zero indicates the 25^{th} percentile, a line within the box marks the median, and the boundary farthest from zero indicates the 75^{th} percentile. Whiskers (error bars) above and below the box show the 90^{th} and 10^{th} percentiles. Outlying points are shown as solid dots.

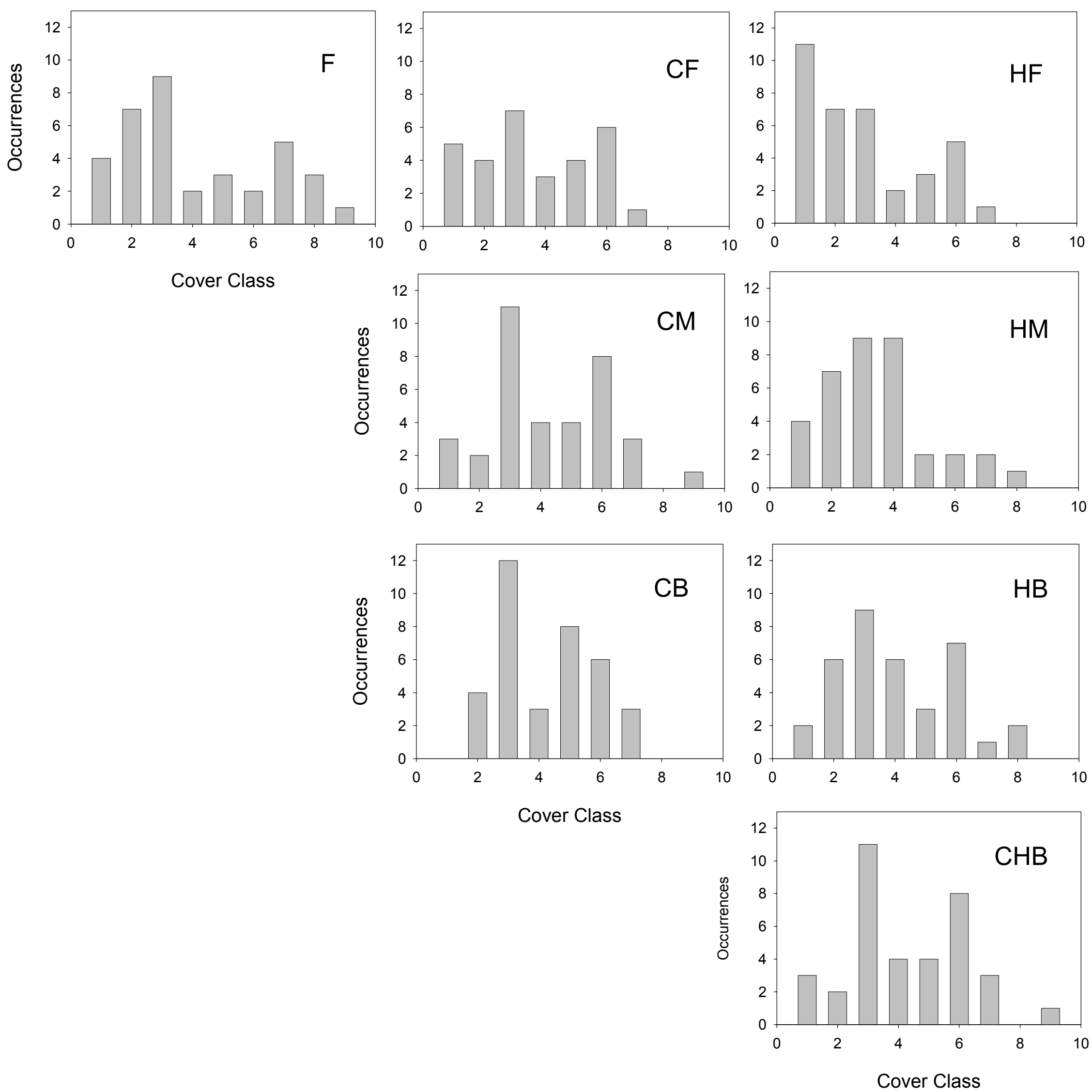

Figure 3.5.4. Frequency of percent burned observations by treatment. Total observations per treatment = 36. Cover classes are defined as follows: 1= 0% burned, 2=trace-1%, 2=2-5%, 3=6-10%, 4=11-25%, 5=26-50%, 7=51-75%, 8=76-95%, 9=96-100%.

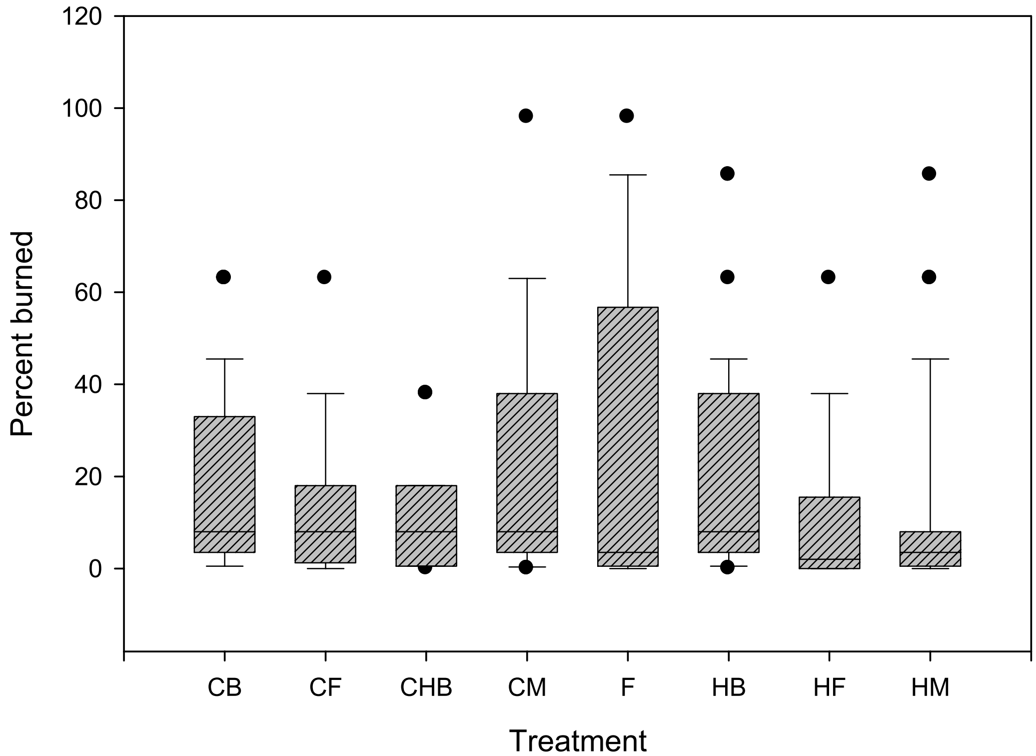

Figure 3.5.5. Mean percent burned in 1-square meter samples by treatment. (n=36 per treatment) The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box show the 90th and 10th percentiles. Outlying points are shown as solid dots.

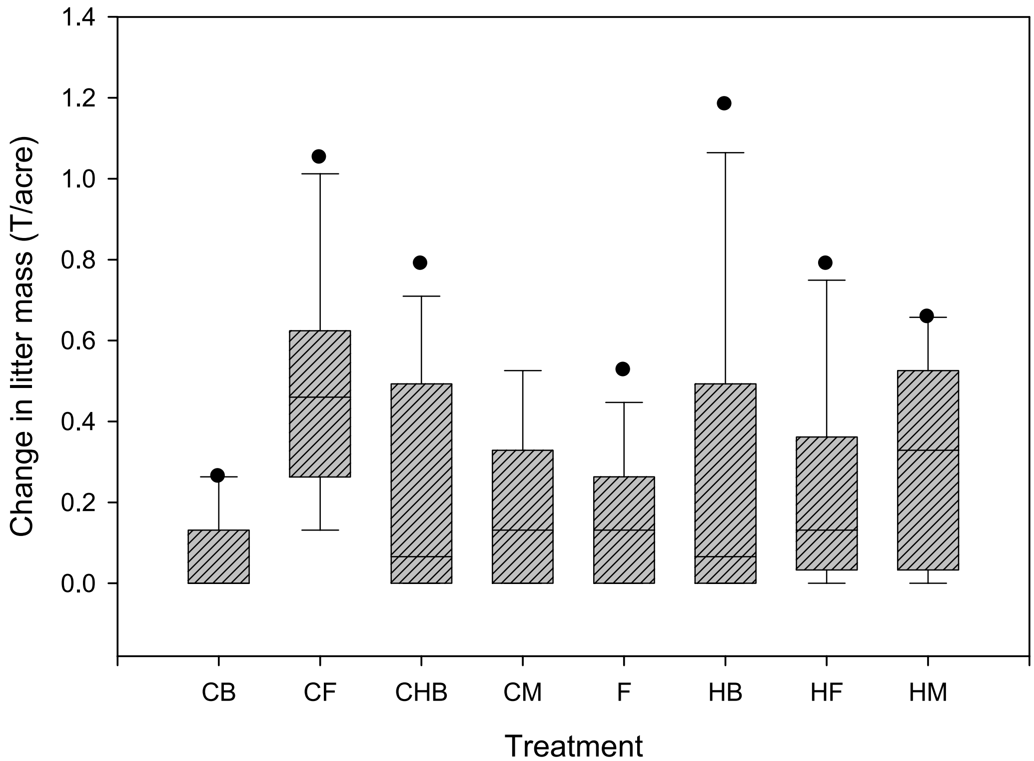

Figure 3.5.6. Change in litter mass by treatment. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box show the 90th and 10th percentiles. Outlying points are shown as solid dots.

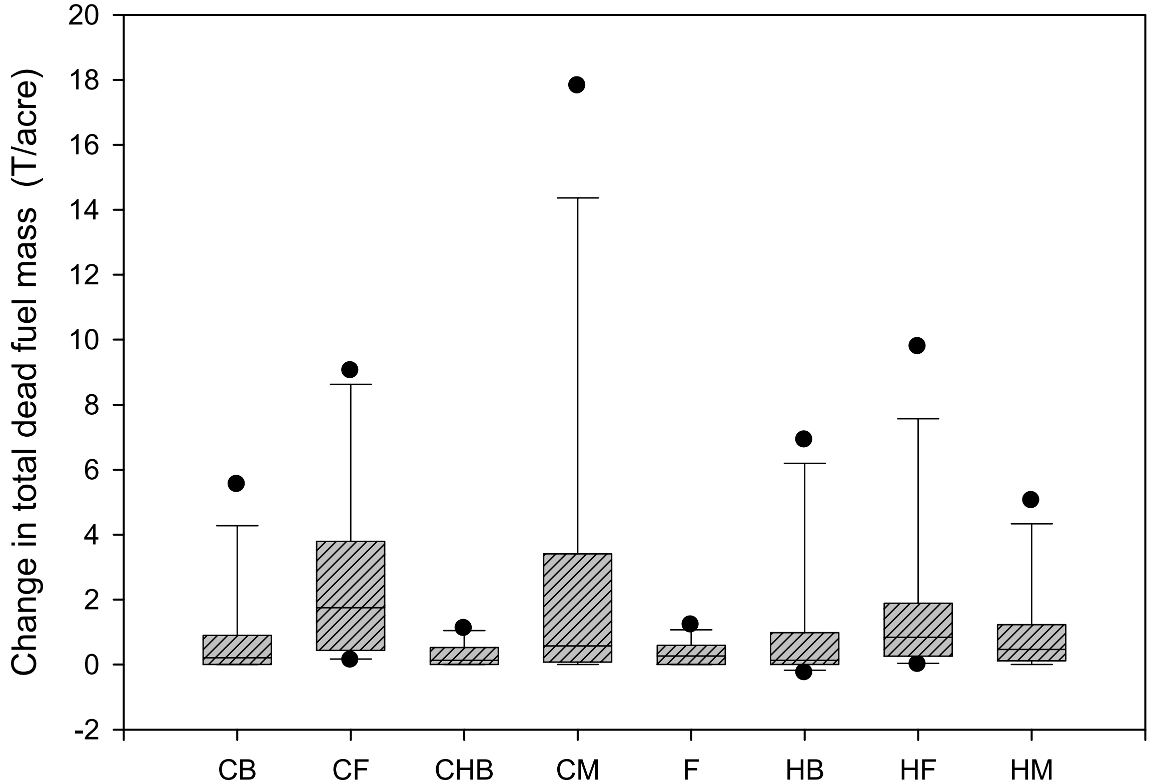

Figure 3.5.7. Change in total fuel mass by treatment. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box show the 90th and 10th percentiles. Outlying points are shown as solid dots.

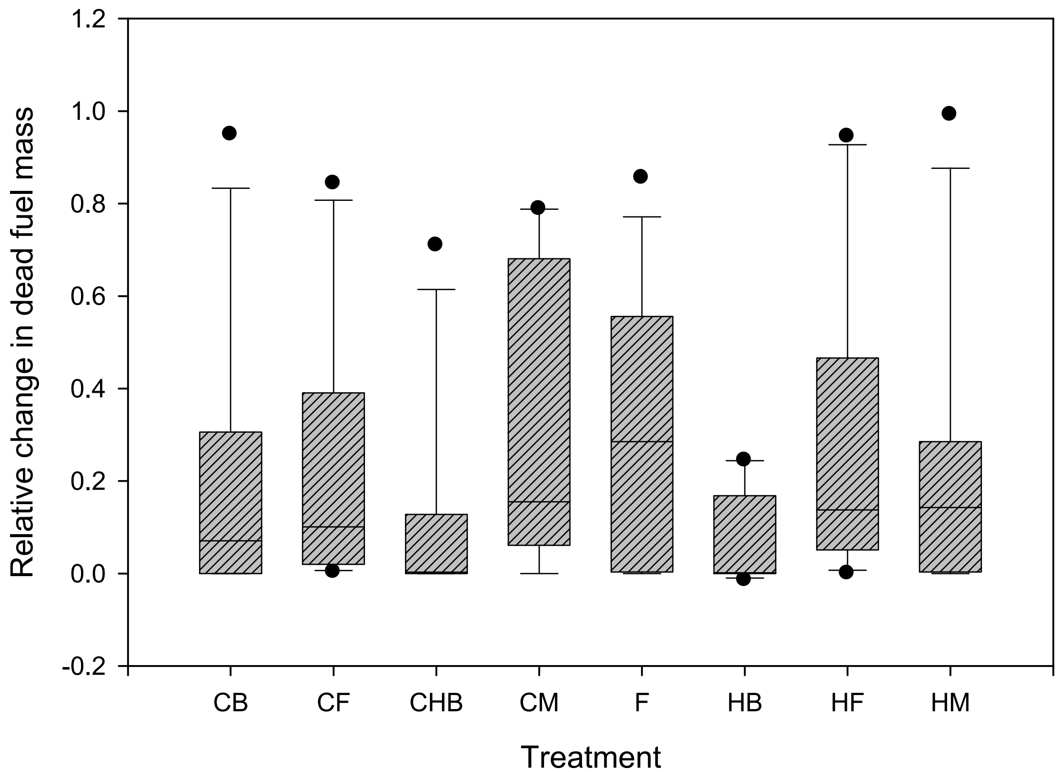

Figure 3.5.8. Relative change in fuel mass by treatment. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box show the 90th and 10th percentiles. Outlying points are shown as solid dots.

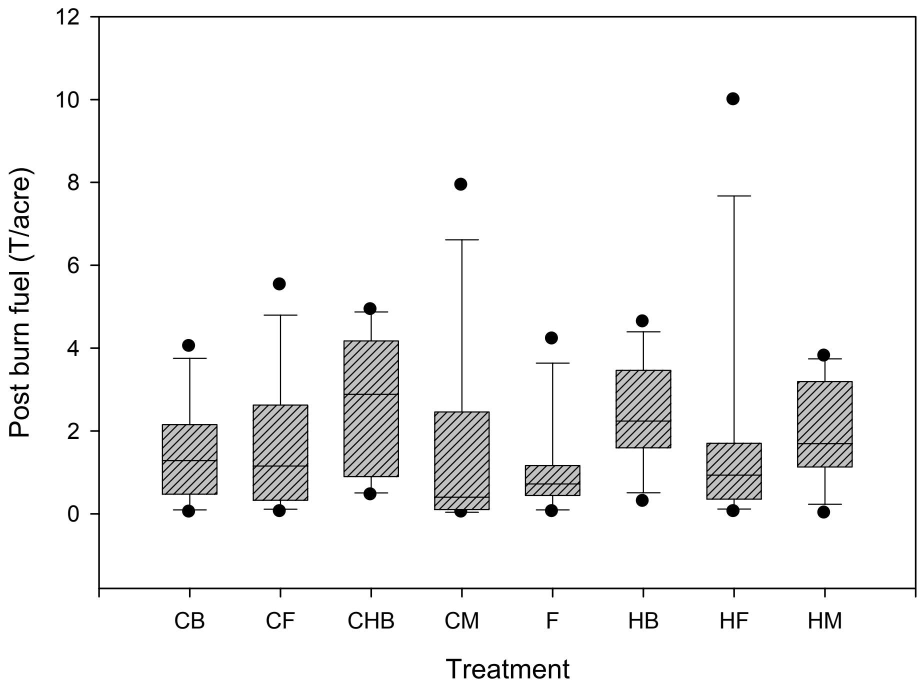

Figure 3.5.9. Post burn fuel mass by treatment. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box show the 90th and 10th percentiles. Outlying points are shown as solid dots.

4. Long-term effects of Longleaf Pine Plantation Establishment

This section contains detailed reports of results and accomplishments related to research Question 2. First, the a comparison of plantations with remnant natural areas (ecological reference sites) is presented including brief introduction, sampling methods, analytical approaches, and results related to Objective 4 (Section 4.1).

Two sections of this report address Objective 5 which specified the development of a conceptual model to relate aspects of plantation establishment and management to the development and management of threatened and endangered species habitats. Section 4.2 presents the results of an effort to address the effects of site preparation treatments on early pine seedling growth on the rate of plantation development. Specifically, existing growth and yield models were adapted and combined to estimate the time needed for plantations to grow trees suitable for RCW foraging habitat. Section 4.3 discusses the project results, first in the context of suitable red-cockaded woodpecker foraging habitat and then with respect to other TERS species at Camp Lejeune. Sections 4.2 and 4.3 provide a framework for integrating results and framing future research needs.

4.1 Composition and structure of managed pine stands compared to reference longleaf pine sites on Camp Lejeune in the outer coastal plain of North Carolina, USA

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4.1.1. Introduction

At the time of European settlement, longleaf pines dominated or co-dominated forests on about 37 million hectares (92 million acres) (Frost 1993). During the centuries following settlement, large areas were lost to agriculture, pasture, and development. The condition of the remaining longleaf forests, about 3.3 million acres in 1994 (Outcalt and Sheffield 1996), has been altered by plantation establishment and fire suppression. Historical land uses have also fragmented the longleaf landscape. Few intact parcels remain, and the current distribution of the endangered red-cockaded woodpecker (RCW) is correlated with remaining large tracts. The largest RCW populations are found on Federal lands (USDI FWS 2003). Longleaf pine habitat loss, fragmentation, and degradation have been cited as contributing factors for the listing of at least 10 animals and 26 plants as federally endangered or threatened. Federal land mangers have responsibilities for promoting the recovery of these listed species.

The ground layer vegetation is a unique and functionally important component of longleaf pine plant communities. On frequently burned sites, mixtures of grasses, forbs, and low shrubs dominate this layer. Although the composition of ground layer vegetation varies regionally, throughout the range site moisture and soil type strongly affect local

composition. The mesic savanna communities of the Atlantic and Gulf coastal plains are remarkable for their botanically interesting plant species, such as orchids and carnivorous plants, and for their extraordinarily high levels of species richness (Walker and Peet 1983, Peet and Allard 1993, Walker 1993). In terms of ecosystem function, the ground layer provides fine fuels to carry the surface fires that sustain the entire ecosystem, and evidence indicates it supports a diverse arthropod community (Folkerts et al. 1993, Hermann et al. 1998, Hanula and Engstrom 2000). Further, recent research reports link the condition of ground layer vegetation to red-cockaded woodpecker (RCW) fecundity and population health. RCW groups defending territories with predominantly grassy or herbaceous ground layers had higher fecundity than nearby groups in shrub-dominated territories (James et al. 1997, Hardesty et al. 1997).

The current Southeastern landscape has hundreds of thousands of acres in pine plantations on sites once dominated by longleaf pine, and it is clear that plantation establishment and management will continue to be effective systems for increasing pine habitat. While there is considerable information available about the effects of plantation establishment, especially about site preparation methods and early growth, the longer-term effects of plantation establishment on ground layer vegetation are not well-documented. Walker and van Eerden (1996) and Smith et al. (2002) report reduced species richness at small scales in plantations (30-40 years old) compared to remnant sites in the fall line sandhills. At scales of 0.1 ha species richness in xeric site plantations nearly equaled remnant sites, however several key ground cover species were significantly reduced. The cover of the dominant bunch grass, *Aristida stricta*, and the dominant dwarf shrub, *Gaylussacia dumosa* were reduced in xeric longleaf pine plantations in Chesterfield County, SC (Walker, unpublished data). Smith et al. (2002) report a similar pattern across a moisture gradient at the Savannah River Site, SC. Additionally, they found that the deviation from remnant condition increased with soil moisture status. That is, the relative difference between mesic plantations and comparable undisturbed vegetation was greater than that difference on xeric sites. These observations suggest that the effects of plantation establishment are likely to be greater as site productivity increases; however, there is no information available to examine this hypothesis on mesic to wet-mesic sites. Understanding this relationship is important if we are to develop site-specific restoration protocols.

This study was undertaken to investigate the potential persistent or cumulative effects of pine plantation establishment and growth on site conditions that range from well-drained to somewhat poorly drained sites historically occupied by longleaf pine communities. We approached the problem by comparing established plantations with remnant longleaf pine communities on similar site types.

4.1.2. Methods

Study area

Marine Corps Base Camp Lejeune (MCBCL) near Jacksonville, NC, occupies 50,585 ha (125,000 acres) in the Atlantic Coastal Flatlands Section of the Outer Coastal Plains

Mixed Forest Province (Bailey 1995, USMC 2001). The Atlantic Ocean forms its eastern border and the New River inlet is a dominant feature in the center of the base. Camp Lejeune has both gently rolling better-drained terrain and poorly drained broad, level flatlands. East of the New River, the flatlands range in elevation from 7.6-13.7 m. Between New River and US 17, the changes in elevation are more pronounced, with 3 areas reaching 22.0 m. West of US 17, in the Greater Sandy Run Area (GSRA), elevation ranges from 11.9-21.0 m.

Sites historically dominated by longleaf pine are practically defined by soils. Nearly 30% of the soils east of US 17 are classified as hydric soils, and 75-80 % of the GSRA are hydric soils. Common wet soils that supported longleaf pine or mixed pine communities are Pactolus fine sand, Rains fine sandy loam, Leon fine sand, Woodington loamy fine sand, Stallings loamy fine sand, and Lynchburg fine sandy loam. Non-hydric longleaf site soils are Marvyn fine loamy sand, Norfolk loamy fine sands, Craven fine sandy loam, Goldsboro fine sandy loam, Foreston loamy fine sand, Onslow loamy fine sand, Kureb fine sand, Alpin fine sand, Wando fine sand, and Baymeade fine sand. Frost (2001) describes presettlement vegetation on Leon fine sands as wet longleaf pine savanna.

The natural longleaf vegetation includes wet, mesic, or xeric longleaf or mixed pine savannas. They generally are described as having an open canopy of longleaf or mixed pines (pond pine on wet sites) and a low ground layer that ranges from graminoid dominance with a high diversity of forbs to dwarf shrub dominance with a mixture of graminoids and forbs. The characteristic structure was maintained by a frequent, low intensity, surface fire regime. Historical fire return intervals are estimated at 1-3 years (Frost 2001).

Recent management has included prescribed burning with a return interval that varies somewhat with location on the base. Active ranges burn annually, but burning once in 3 years is more common. Through the 1970s and 1980s the natural resources staff managed pine stands to maintain production using even-aged systems typical of the general forest management practices of the time. Currently, pine stands are regenerated primarily to restore longleaf pine to suitable RCW habitat, but existing plantations are managed to maintain their vigor and economic value. Most of the stands sampled in this study were artificially regenerated, but intensity of site preparation varied. Managed pine stands are burned on rotations with the general forest.

Site selection

Managed pine stands on Camp Lejeune were sampled during the summers of 2003 and 2004. We attempted to sample across the range of site types that historically supported longleaf pine communities from somewhat poorly drained sands through well drained loamy sands on side slopes and hill tops (Frost 2001). Sites were located on the following soil series: Kureb fine sand, Baymeade fine sand, Leon fine sand, Murville fine sand, Norfolk loamy fine sand, Onslow loamy fine sand, Stallings loamy fine sand, Wando fine sand, and Woodington loamy fine sand. We sampled sites at least 18 years old so that we could capture stands where intensive site preparation methods had been

applied; the base began using a bedding plow for site preparation in 1986. By age 18 the canopy had closed, and some stands had received a first thinning, usually a row thinning removing every third row. Beds, if used for site preparation, were clearly evident. Vegetation changes rapidly following fire, and to minimize the effects of this change, we restricted site selection to areas that were burned within 12 months prior to sampling. We include 29 stands in this analysis.

For reference plot data we acquired plot data from the Carolina Vegetation Survey (CVS) vegetation plot database. We selected plots sampled within the boundaries of Camp Lejeune. Reference plots were sampled in 1991 by CVS teams under the direction of R.K. Peet (UNC, Chapel Hill) and T. R. Wentworth (NCSU, Raleigh). Plot data are archived by the Herbarium at the University of North Carolina, Chapel Hill, NC. From all Lejeune plots, we selected 39 plots dominated by longleaf pine, or a mixture of longleaf and loblolly or pond pines. All soil series in reference plots were represented among plantations except Foreston loamy fine sand and Alpin fine sand.

The location of all plots sampled is shown in Figure 4.1.1.

Data collection and calculations

All plots were sampled using the CVS protocol described by Peet et al. (1998). This protocol is based on a 10 m x 10 m module, with an array of 10 modules representing a complete plot sample (0.1 ha) (Figure 4.1.2). Within each intensively sampled module (up to 4 per plot), species presence was recorded in 2 sets of nested subplots sized 0.01-10 m2 and located in opposite corners. Within each plot, rooted vascular plant richness was estimated for six nested areas regularly spaced on a log-10 scale, from 0.01 to 1000 m2 (Figure 4.1.2). Richness values for areas less than 0.1 ha were averaged to estimate richness at the plot level. Species cover was estimated at the module level using cover classes: 10 = 95-100%, 9 = 75-95%, 8 = 50-75%, 6 = 10-25%, 5= 5-10%, 4 = 2-5%, 3 = 1-2%, 2 = <1%, 1 = trace. For analyses, cover class values were converted to the mid-points of cover classes, averaged for the plot, and re-converted to cover classes for analyses. Mean plot abundance and richness at the plot level were used to calculate the Shannon-Weiner diversity index (H') and Simpson's diversity index (D) (Pielou 1969).

In each plot, trees greater than 2.5 cm dbh were tallied by size class and species. We calculated density and basal area for all woody stems combined, for all pines, and for all hardwoods.

Soil samples were (n=5) collected from the top 10 cm of each plot, and pooled for analyses. Soils from managed pine stands were analyzed in the Forestry Sciences Lab, RTP, NC. Soils data from CVS reference sites were analyzed by Brookside Labs, Knoxville, OH. The following soil variables were included in this study: cation exchange capacity (CEC), % base saturation by K^+ (K_{sat}), Mg^{+2} (Mg_{sat}), and Ca^{+2} (Ca_{sat}), pH, organic matter (OM), and extractable K^+, Mg^{+2}, Ca^{+2}. Soil texture is reported as percent sand, silt, and clay.

Vascular plant taxonomic concepts and nomenclature were standardized to follow Kartesz (1999). In order to minimize the effects of possible plant identification inconsistencies between field crews, especially of difficult plant groups (e.g. vegetative *Dichanthelium* spp.) we combined taxa except those we judged to be easily identified correctly by most field botanists. Similarly, to avoid inconsistencies in taxonomy, we did not recognize subspecific taxa.

Data analysis

We used ordination by non-metric multidimensional scaling, or NMS, to represent the variation in ground layer communities in plantations and remnant sites. Tests with simulated data confirm the utility of NMS for extracting main axes of variations in vegetation data (Minchin 1987, Clarke 1993). We used the Bray-Curtis dissimilarity index (Bray and Curtis 1957). Ordinations were performed with the number of dimensions ranging from 1 through 6; and to avoid local minima, 40 different random staring configurations were used. A Monte Carlo test based on 50 randomizations of the vegetation data matrix was used to determine the probability that a similar final stress could have been obtained by chance. We ran the procedure for 400 interations to get the final solution with real data. We examined the scree plot (line graph of minimum stress versus number of dimensions) to identify the number of dimensions beyond which further reductions in stress were relatively minor (Kruskal 1964; Kruskal and Wish 1978).

We tested for community differences between plantations and remnant sites using MRPP (Multi-Response Permutation Procedure) (Mielke 1984, Mielke and Berry 2001, Biondini et al. 1985). MRPP is a non-parametric procedure for testing the hypothesis of no difference between two or more groups of entities, in this case between entries in a distance matrix. To be consistent with NMS ordinations we used the Bray-Curtis distance measure for MRPP. The value of A, the chance-corrected within-group agreement, describes within-group homogeneity, compared to the random expectation. When all items are identical within groups, $A = 1$; if heterogeneity within groups equals expectation by chance, then $A=0$; if there is less agreement within groups then expected by chance, then $A<0$. $A>0.3$ is fairly high for ecological data (McCune and Grace 2002). A permutation procedure was used to test how likely the difference in mean distance between groups result is by chance.

Indicator Species Analysis (ISA; Dufrene and Legendre 1997) was used to identify the species that best discriminated the groups. Significance of the Indicator Value (IV) was tested by random permutation with 1000 trials.

NMS, MRPP, and ISA were performed using PC-ORD version 4 (McCune and Mefford 1999).

We used ANOVA techniques (PROC GLM; SAS/STAT™ software, Release 8.1 for WINDOWS; Copyright©2000, SAS Institute Inc. Cary, NC, USA) to test for a site type (reference versus managed pine) effect on density and basal area of all woody species, of pines, and of hardwoods. Single factor ANOVA was also used to test for a site type

effect on species richness at various spatial scales, on environmental variables, and on percent cover of selected species and of species growth form groups (woody species, herbaceous species).

4.1.3. Results

The NMS ordination resulted in 3 dimensions as optimal (lowest stress) for representing the variation in the plot data. The proportion of variance represented by each axis, calculated as the correlation r^2 between distance in the ordination space and distance in the original space, is shown in Table 4.1.1. Correlations of environmental and structural data were generally low (Table 4.1.2). Because pH was the only explanatory variable associated with Axis 2 with an $r^2>0.15$, and Axis 2 represented the least variance in the data, we show the array of plots on Axes 1 and 3 only **(**Figure 4.1.3)**.** In general, position on Axis 1 was correlated positively with stand age, Mg_{sat}, and Ca_{sat} , and negatively with the basal area of pines and total basal area, and K^+. Axis 3 was related most strongly with measures of plot diversity, S, H', and D.

MRPP generated a low A =0.06, but the difference was statistically significant at $p<0.0001$. A low A suggests that the differences within groups were not much greater than that expected by chance alone. This may result from the high variability among the managed pine stands, making it difficult for actual data to differ from randomly generated data in the permutation procedure. The result is consistent with the separation of groups within NMS (Figure 4.1.3).

The most reliable indicators ($p\leq 0.01$) of reference sites included species characteristic of well-burned longleaf pine communities, especially *Pinus palustris*, the geographically restricted bunchgrasses *Aristida stricta* and *Sporobolus pinetorum*, low shrubs *Gaylussacia dumosa* and *G. frondosa*, and a variety of forbs (Table 4.1.3). Forbs comprised 42% of the reliable indicators in reference plots. Indicators in managed pine stands included species generally considered weedy or even off-site species such as *Pinus elliottii*, *Schizachyrium scoparium*, *Erechtites hieraciifolia*, and *Rubus argutus*. Shrubs and forbs were almost equally represented (24 and 29%), and vines, not present in the reference sites, were identified as indicators of planted pine sites.

Site type had a significant effect ($p<0.0001$) on species richness at scales of 0.1 m^2, 1 m^2 and 10 m^2, such that reference sites richness exceeded richness in managed pine stands (Figure 4.1.4). At spatial scales of 100 and 1000 m^2, differences between site types were not significant. The log of richness increased linearly with the log of area sampled, though there was no difference in the slopes of the regressions for plantations compared to reference sites.

Plantations differed from reference plots in both soil chemistry and community structure (Table 4.1.4). Compared to reference sites, plantation soils had higher organic matter contents and CEC, and higher pH. Reference soils had marginally higher extractable Ca^{+2}, but did not differ in K^+ and Mg^{+2}. We found that plantations had significantly higher pine density and basal area, but hardwood abundance in the canopy was not

different between the groups. Plantations and reference sites were not different with respect to three measure of ground layer vegetation structure (S, H', D) but there was a site type effect on evenness (E).

The total ground cover in reference sites exceeded that in plantations (113% versus 81%; Table 4.1.5). The difference was mostly in the herbaceous component which had almost double the cover in remnants compared to plantations (43% vs. 24%). *Aristida stricta*, *Gaylussacia dum*osa and *Pinus palu*stris were more abundant in reference sites than in plantations by factors of 5, 10 and 6 respectively. *Gaylussacia frondosa*, which is similar to *G. dumosa* in growth form but tends to be more abundant on wetter sites than *G. dumosa*, was not different between the site types.

4.1.4. Discussion

Overall, plantations (≥18 years old) differ compositionally and structurally from ecological reference sites. The loss of potentially dominant groundcover species, such as *Aristida stricta*, *Gaylussacia dumosa*, and *Pinus palustris* seedlings, is consistent with observations in similar comparisons of plantations compared to reference stands in the sandhills of South Carolina (Smith et al 2002; Walker, unpublished data). In sandhills plantations, species composition was similar to reference sites, except for the conspicuous losses of *A. stricta* and *G. dumosa*. As in the Camp Lejeune study, sandhills plantations had significantly higher pine densities and basal areas than comparable reference sites. The reduced herbaceous cover and increased pine density suggest that plantations as a group do not provide high quality foraging opportunities for red-cockaded woodpeckers (USDI FWS 2003); this relationship is discussed in more detail in **Section 5** of this report.

The lack of difference in species richness except at the smallest scales indicates that reasonably diverse communities are maintained in plantations, and suggests the potential for restoring a diverse groundcover without adding species. However, as noted previously, a few dominant species apparently are sensitive to habitat modifications created during establishment and growth of plantations. Although thinning the canopy and prescribed burning may invigorate the groundcover (Provencher et al. 2001), we predict that the effectiveness of prescribed burning may be limited by the lack of fine fuels resulting from the significantly reduced herbaceous cover in plantations. Restoring the continuity of fine fuels is likely to require reintroducing the dominant large graminoids indicative of reference sites.

We expected stronger relationships between ordination scores and environmental parameters; specifically, we expected stands would be ordered strongly by soil texture. The relationship of composition to soil texture, widely regarded as a surrogate for soil moisture availability, is well-established for natural stands (Walker and Peet 1983, Christensen 1988, Taggart 1990, Peet and Allard 1993). We predict that an analysis of the reference sites alone would reveal a compositional gradient that follows soil texture, but that such a relationship would not be found in an analysis of plantations. In a comparison of plantations and reference sites in the Fall-line sandhills of South Carolina,

Smith et al (2002) reported that the expected strong relationship between ground layer composition and soil texture was evident for both plantations and reference natural areas; however, the difference between plantations and reference sites was greater at the mesic end of the environmental gradient than in xeric sites. We hypothesize that plantations on wet sites are inherently more variable than on drier sites, initially because establishment methods are more variable, and early stand management varies with the species of pine planted. In the rapid and profound changes that occur on wet sites, characteristic species are lost to more widespread weedy ones, both herbaceous and woody, thereby obscuring species habitat relationships that govern species distributions in the undisturbed landscape.

4.1.5. Conclusions

Existing plantations at Camp Lejeune differ from ecological reference sites both compositionally and structurally. The structure of existing plantations (≥ 18 years old) does not meet the guidelines for red-cockaded woodpecker foraging habitat. Although the plantations will meet pine size and age requirements through time, meeting the groundcover standard for >40% cover of desirable native grasses and forbs may require planting native grasses.

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Tables and Figures

Table 4.1.1. Coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space. Increment and cumulative R-squared were adjusted for any lack of orthogonality of axes. A total of 67 plots and 2211 between plot distances were used in this correlation. The distance measure for the original distance was Bray-Curtis (Sorenson).

	R Squared	
Axis	Increment	Cumulative
1	.426	.426
2	.205	.632
3	.252	.884

Table 4.1.2. Pearson and Kendall correlations of environmental and stand structural parameters with NMS ordination axes. S= # of species/0.1 ha, E = Evenness index, H= Shannon-Weiner diversity index, D'= Simpson's index of diversity for an infinite population (McCune and Grace 2002). (Measures of diversity were calculated using PC-ORD Version 4.)

Axis:	1			2			3		
Variable	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
Age, yr	0.661	0.437	0.522	-0.19	0.036	-0.101	-0.227	0.051	-0.162
CEC, μeq	-0.327	0.107	-0.19	0.391	0.153	0.257	0.254	0.064	0.188
Ksat, %	-0.027	0.001	0.278	-0.021	0	-0.049	-0.146	0.021	-0.128
Mgsat, %	0.585	0.342	0.416	-0.133	0.018	-0.117	-0.289	0.083	-0.227
Casat, %	0.503	0.253	0.298	-0.304	0.092	-0.294	-0.253	0.064	-0.263
pH	-0.375	0.141	-0.331	-0.358	0.128	-0.281	0.069	0.005	0.027
OM, %	-0.367	0.135	-0.368	0.272	0.074	0.147	0.256	0.065	0.208
K, ppm	-0.427	0.183	-0.186	0.21	0.044	0.24	0.079	0.006	0.087
Mg, ppm	0.209	0.044	0.136	0.342	0.117	0.172	0.167	0.028	0.027
Ca, ppm	0.195	0.038	0.16	0.073	0.005	-0.091	0.146	0.021	-0.085
Clay, %	0.068	0.005	0.028	-0.264	0.07	-0.135	-0.072	0.005	0.002
Silt, %	-0.201	0.041	-0.059	0.124	0.015	0.034	0.208	0.043	0.093
Sand, %	0.191	0.036	0.059	-0.101	0.01	-0.034	-0.197	0.039	-0.093
Total tree density, #/ha	-0.179	0.032	-0.275	0.201	0.04	0.209	-0.026	0.001	0.063
Total basal area, m^2/ha	-0.425	0.181	-0.405	-0.041	0.002	-0.059	-0.021	0	0.033
Pine density, #/ha	-0.26	0.067	-0.193	0.106	0.011	0.231	-0.028	0.001	0.17
Pine Basal area, m^2/ha	-0.426	0.181	-0.355	-0.017	0	-0.006	0.015	0	0.1
Hardwood density, #/ha	0.002	0	-0.181	0.222	0.049	0.033	-0.036	0.001	-0.076
Hrdwd basal area, m^2/ha	-0.166	0.027	-0.212	-0.156	0.024	-0.117	-0.22	0.048	-0.152
S	0.054	0.003	0.005	-0.005	0	-0.033	0.572	0.327	0.403
E	-0.083	0.007	-0.064	-0.04	0.002	-0.032	0.471	0.222	0.339
H'	0.042	0.002	-0.007	-0.01	0	-0.042	0.58	0.337	0.416
D	0.052	0.003	-0.017	-0.016	0	-0.047	0.539	0.291	0.432

Table 4.1.3. Indicator taxa for the ground layer vegetation in two groups of plots: reference plots and managed pine stands. Tabulated indicator values (IV) are percentages that combine relative abundance (average abundance of a given species in a given group of plots/ the average abundance of that species in all plots expressed as a %) and relative frequency ((% of plots in given group where given species is present). Probabilities (*p*) are derived from 1,000 trials in which plots were randomly allocated between groups. Scores for significant indicators (p≤ 0.05) are ordered by significance of the p-value. Species with IV greater ≥ 40 are in **bold type**.

Reference Indicators	GF	Obs. IV	*p*	Plantation Indicators	GF	Obs. IV	*p*
Andropogon ternarius	**graminoid**	**71.2**	**0.001**	***Erechtites hieraciifolia***	**forb**	**40**	**0.001**
Aristida stricta	**graminoid**	**70.2**	**0.001**	***Gelsemium sempervirens***	**vine**	**72.9**	**0.001**
Gaylussacia dumosa	**shrub**	**70**	**0.001**	***Ilex opaca***	**shrub**	**53.1**	**0.001**
Ionactis linariifolius	**forb**	**55.2**	**0.001**	*Panicum anceps*	graminoid	25	0.001
Pinus palustris	**tree**	**73.2**	**0.001**	*Pinus elliottii*	tree	32.1	0.001
Pinus serotina	**tree**	**47.5**	**0.001**	***Schizachyrium scoparium***	**graminoid**	**42.9**	**0.001**
Quercus incana	tree	39.9	0.001	*Scleria sp*	graminoid	27.3	0.001
Rhynchospora baldwinii	graminoid	35.9	0.001	***Solidago odora***	**forb**	**42.9**	**0.001**
Solidago pulchra	**forb**	**61.5**	**0.001**	***Vitis rotundifolia***	**vine**	**41.6**	**0.001**
Carphephorus odoratissimus	**forb**	**56.3**	**0.002**	*Prunus serotina*	tree	21.4	0.003
Euphorbia ipecacuanhae	forb	35.3	0.003	*Rubus argutus*	shrub	21.4	0.003
Sporobolus pinetorum	graminoid	33.3	0.003	*Symphyotrichum dumosum*	forb	23.9	0.006
Carphephorus paniculatus	forb	28.2	0.004	***Smilax glauca***	**vine**	**54.7**	**0.007**
Hypericum reductum	shrub	29.3	0.006	*Euthamia tenuifolia*	forb	21.4	0.008
Vaccinium tenellum	**shrub**	**58.8**	**0.006**	*Galactia regularis*	forb	36.4	0.008
Gaylussacia frondosa	**shrub**	**57.9**	**0.007**	*Ilex vomitoria*	shrub	17.9	0.009
Lespedeza angustifolia	forb	25.6	0.008	*Rhus glabra*	shrub	17.9	0.01
Rhexia alifanus	forb	38	0.008	***Liquidambar styraciflua***	**tree**	**46.8**	**0.012**
Galactia erecta	forb	23.1	0.009	*Parthenocissus quinquefolia*	vine	17.9	0.012
Sericocarpus tortifolius	**forb**	**41.4**	**0.02**	*Bignonia capreolata*	vine	17.9	0.013
Vaccinium formosum	shrub	26.7	0.024	*Rubus cuneifolius*	shrub	28.5	0.014
Cleistes divaricata	forb	26.3	0.027	*Rubus trivialis*	shrub	17.9	0.014
Desmodium tenuifolium	forb	22.2	0.028	*Cyperus sp*	graminoid	17.9	0.017
Rubus flagellaris	shrub	17.9	0.031	*Quercus geminata*	tree	19.1	0.022
Iris verna	**forb**	**46.7**	**0.033**	*Solidago leavenworthii*	forb	14.3	0.022
Carphephorus tomentosus	forb	20	0.034	*Baccharis halimifolia*	shrub	14.3	0.024
Centella asiatica	forb	17.9	0.034	*Smilax rotundifolia*	vine	30	0.024
Panicum virgatum	graminoid	17.9	0.034	*Paspalum setaceum*	graminoid	19.1	0.026
Rhynchospora globularis	graminoid	17.9	0.035	*Acer rubrum*	tree	30	0.027
Quercus hemisphaerica	tree	17.9	0.038	*Hypoxis sp*	forb	18.2	0.03
Xyris caroliniana	forb	34.7	0.04	*Tephrosia spicata*	forb	14.3	0.03
				Clitoria mariana	forb	14.3	0.032
				Liriodendron tulipifera	tree	14.3	0.032
				Aristida virgata	graminoid	14.3	0.033
				Chimaphila maculata	forb	14.3	0.035
				Hieracium spp.	forb	21.5	0.035
				Persea borbonia	**tree**	**49.2**	**0.035**
				Rhynchospora chapmanii	graminoid	15.4	0.047

Table 4.1.4. Summary of soil characteristics and structural variables used in secondary matrix of ordination. All values are means (1SE). F and p values are results of one factor ANOVA testing for effect of stand type (plantation vs. remnant) on variable mean. Degrees of freedom = 1 for all tests.

Variable	**Remnant mean(SE)**	**Plantation mean(SE)**	**F**	**p**
pH	3.95(0.05)	4.18(0.05)	8.83	0.0042
CEC (μeq)	6.67(0.62)	11.11(0.96)	16.43	0.001
OM (%)	0.57(0.15)	1.57(0.14)	22.64	<0.0001
Ca (mg/kg or ppm)	226.70(25.8)	163.19(15.28)	3.79	0.056
K (mg/kg or ppm)	21.79(1.86)	38.10(3.56)	19.10	<0.0001
Mg (mg/kg or ppm)	48.72(4.31)	42.89(3.54)	0.97	0.328
Ca saturation (%)	17.40(0.86)	5.50(0.79)	94.97	<0.0001
K saturation (%)	0.93(0.06)	0.82(0.23)	0.29	0.593
Mg saturation (%)	6.34(0.19)	2.32(0.34)	118.10	<0.0001
Total tree density (stems/ha)	647.77(167.0)	1376(335.2)	4.45	0.039
Total tree basal area (m^2/ha)	11.34(0.72)	23.07(4.31)	9.84	0.003
Pine density (stems/ha)	298.57(37.3)	971.09(234.2)	11.01	0.0015
Hardwood density (stems/ha)	349.19(154.0)	373.26(120.11)	0.01	0.908
Pine basal area (m^2/ha)	9.98(0.75)	21.17(3.98)	10.36	0.002
Hardwood basal area (m^2/ha)	1.36(0.38)	1.89(0.54)	0.67	0.417
Species richness (S)	54.51(2.90)	53.18(3.01)	0.10	0.756
Species diversity (H)	3.81(0.06)	3.82(0.07)	0.01	0.929
Species Diversity (D)	0.97(0.002)	0.97(0.002)	0.01	0.905
Evenness (E)	0.96(0.002)	0.97(0.002)	4.30	0.042

Table 4.1.5. Mean (SE) cover (% cover) in the ground layer vegetation (< 1 m tall) of (a) herbaceous, woody and all species and (b) selected species in plantations and remnant forests. n=28 for plantations, n=39 for remnants. F and p values are from one factor analysis of variance testing for differences in the mean cover of each category in plantations and remnants. Degrees of freedom = 1 for all tests.

(a) Growth form group	**Plantation mean (SE), %**	**Remnant mean (SE), %**	**F**	**p**
Herbaceous species	23.79(2.79)	43.20(4.48)	11.17	0.0014
Woody species	56.98(6.31)	70.04(6.05)	2.14	0.1480
Total cover	80.77(7.37)	113.24(6.12)	11.54	0.0012
(b) Selected species				
Aristida stricta	4.02(1.54)	21.83(3.82)	14.36	0.0003
Gaylussacia dumosa	0.51(0.11)	9.06(1.98)	13.36	0.0005
Gaylussacia frondosa	4.05(1.14)	7.95(1.53)	3.61	0.620
Pinus palustris	2.50(0.92)	15.28(2.59)	16.39	0.0001

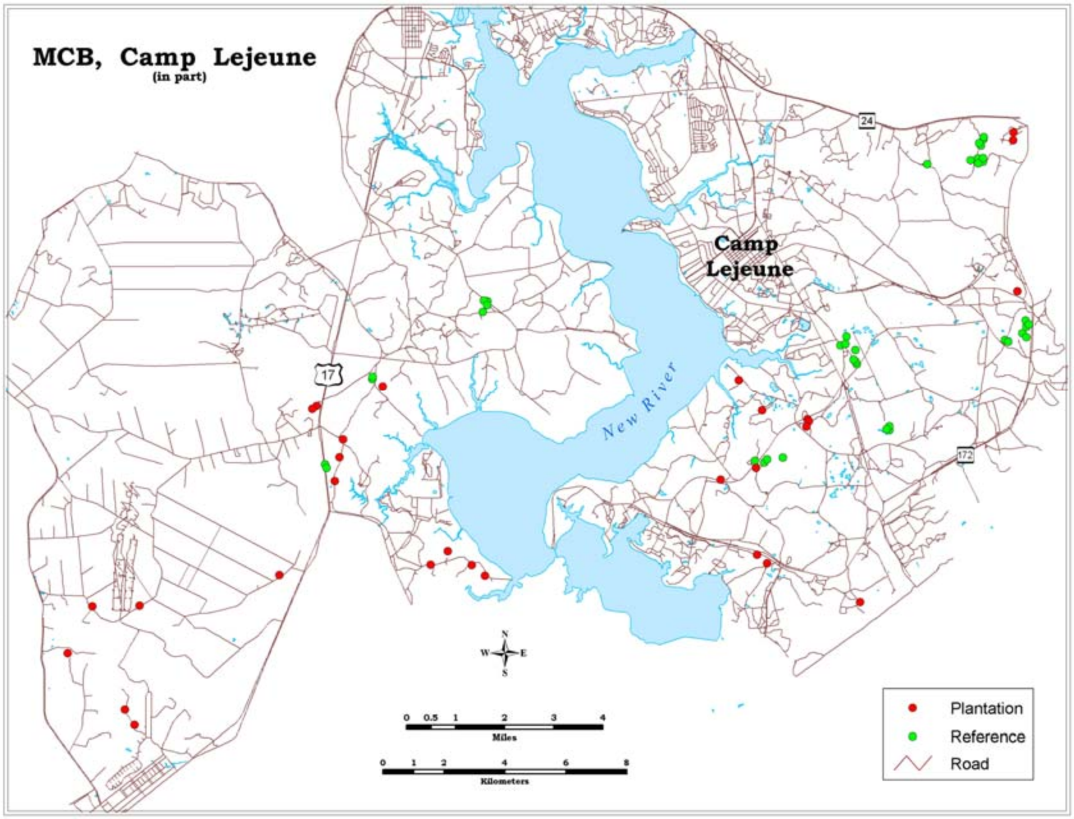

Figure 4.1.1. Plantation and reference plot locations within Camp Lejeune.

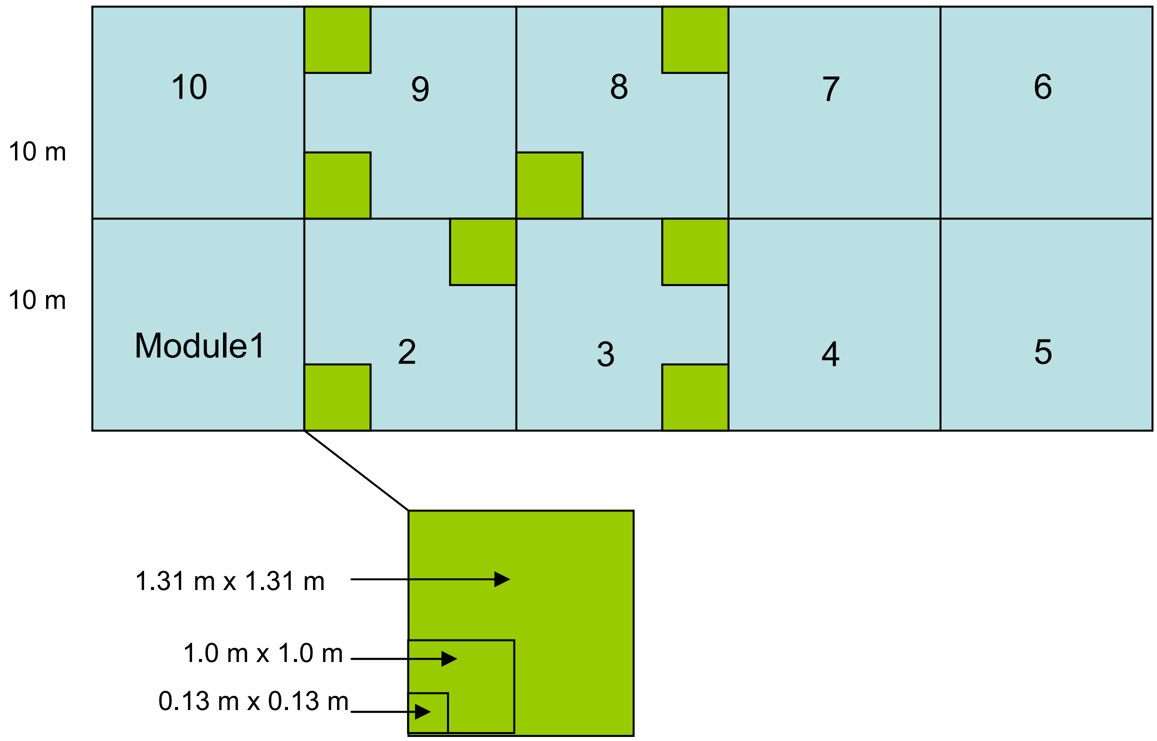

Figure 4.1.2. Vegetation sampling design includes nested plots ranging in size from 0.10 – 1000 m^2. The largest plot contains 10 sampling modules, four sampled with nested plots. Soils are sampled (0-10 cm depth) near the centers of four modules and composited; one subsoil sample is taken.

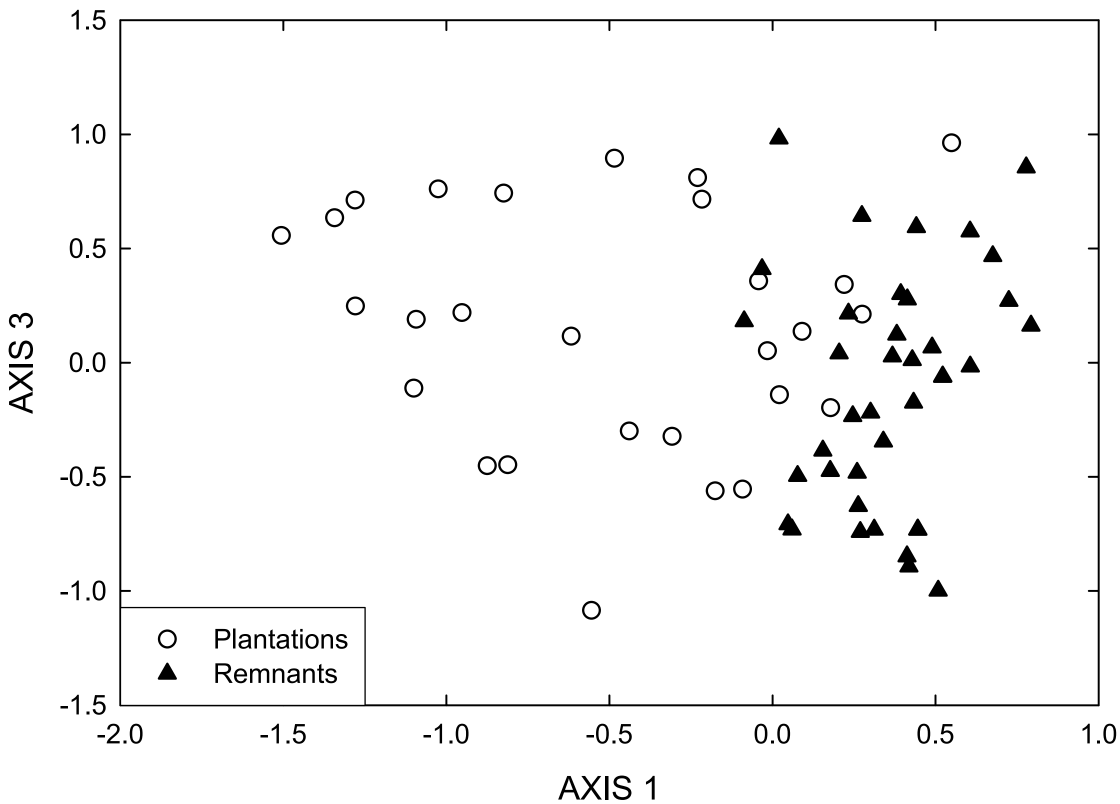

Figure 4.1.3. Results of ordination of vegetation community data by non-metric multidimensional scaling (NMS).

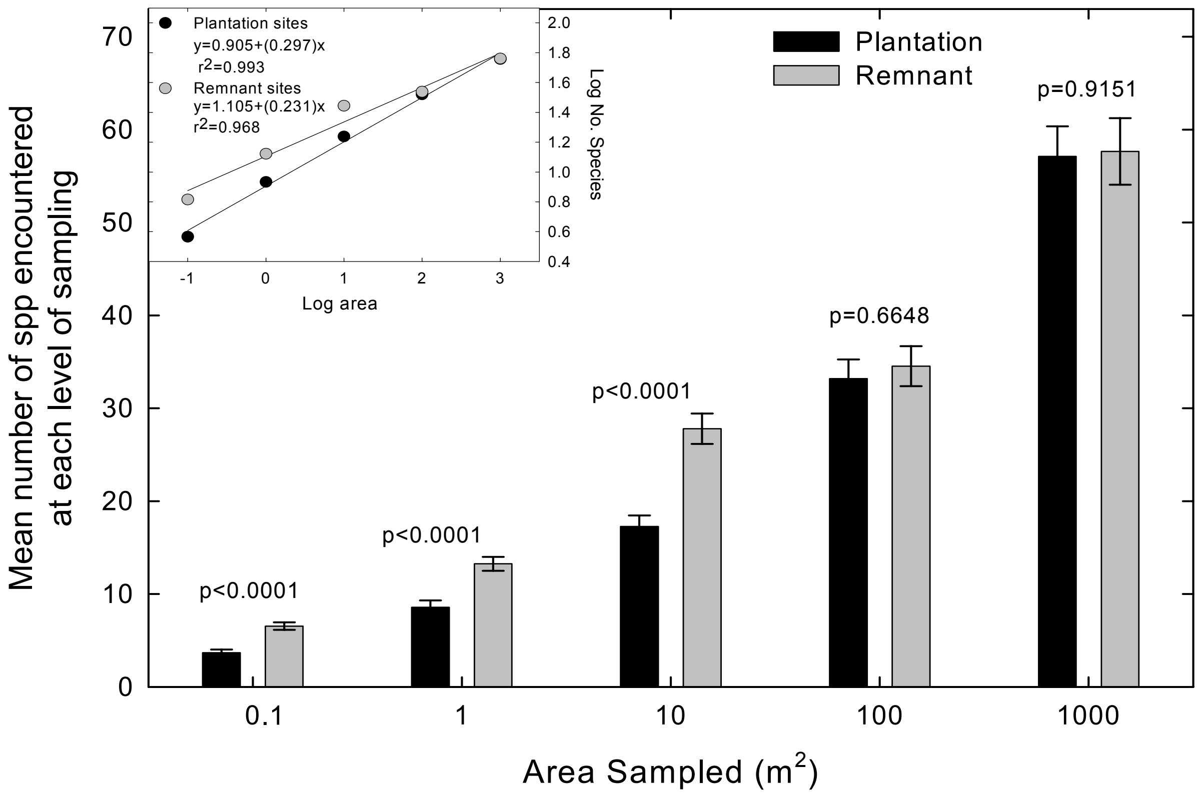

Figure 4.1.4. Species richness (number of species counted) at five different sampling scales in plantations and remnant sites. Shown are means(±1SE). P-values above pairs of bars indicate result of one-way ANOVAs testing the effect of site type (plantation vs remnant) on species richness at each scale. Inset shows the relationship between the log of the area sampled and the log of the number of species in both plantations and remnant sites. Lines show results of simple linear regression between log of area sampled and the log of the number of species for each site type. Regression equations and r^2 are given for each type of site.

4.2. Using existing growth models to predict RCW habitat development following site preparation: pitfalls of the process and potential growth response

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4.2.1 Introduction

Throughout the southeastern United States, forest managers on lands supporting red-cockaded woodpeckers (RCWs; *Picoides borealis*) are increasingly interested in maintaining or creating RCW habitat. Favorable RCW habitat is commonly associated with a canopy dominated by longleaf pine (*Pinus palustris* Mill.), but historical land use and management practices have resulted in widespread conversion of longleaf pine forests to forests dominated by faster growing species such as loblolly pine (*Pinus taeda* L.) (Frost 1993). To increase RCW habitat quality, many land managers are now interested in rapidly re-establishing longleaf pine on sites dominated by other species.

Site preparation treatments are potentially useful management tools for increasing tree growth. Because site preparation is typically a single event that takes place just before seedlings are planted, seedling response is the strongest, and most often quantified, in the early years of stand establishment. A number of past studies have demonstrated the effectiveness of site preparation for increasing early growth rates and/or reducing early mortality of planted longleaf pine (e.g. Boyer 1988, Haywood 2007, Knapp and others 2006) and other southern pine seedlings (e.g. Knowe and others 1992, Pritchett 1979, Rahman and Messina 2006). In production forestry, rapid establishment and early growth shortens time to financial maturity and thereby increases the land owners' investment. However, land managers wishing to restore RCW habitat must consider the effects of site preparation on a temporal scale that depends on the ecological requirements of the RCW rather than economic returns.

To facilitate restoration of RCW habitat, site preparation must shorten the time required for a stand to develop from seedlings to trees of the size and structure utilized by RCWs. Although RCWs generally favor older trees in the forest for use as cavity trees (often 80 to 150 years old), stand criteria for good quality foraging habitat may be reached substantially sooner. According to US Fish and Wildlife recovery standard guidelines (U.S. Fish and Wildlife Service 2003), a group of RCWs will use from 49 to 120 ha of forest surrounding cavity trees as foraging habitat, depending on site productivity and habitat quality. Stand structure for good quality foraging habitat includes, but is not limited to: 1) at least 45 pines/ha that are > 35 cm in diameter at breast height (DBH), 60 years old, and total at least 4.6 m^2/ha basal area; 2) basal area of all pines $\geq$ 25 cm DBH is at least 9.2 m^2/ha; and 3) basal area of pines $\leq$ 25 cm DBH is lower than 2.3 m^2/ha and below 50 stems/ha. In general, these guidelines describe stands that are dominated by large, old pines and include low densities of smaller pines or hardwoods. The quality of foraging habitat generally improves with tree size, as indicated by the requirement of a

minimum number of large (> 35 cm DBH), old (≥ 60 years old) trees. However these guidelines suggest that 9.2 m^2/ha basal area of 25 cm DBH trees is an important structural characteristic that may be a threshold for stands becoming RCW foraging habitat. It is not clear when artificially regenerated stands will reach the required structure for foraging habitat, or whether short-term effects of site preparation on longleaf pine seedlings will result in long-term differences in stand establishment.

The objectives of this study were to: 1) project theoretical growth and stand structure following site preparation using existing longleaf pine growth and yield models to predict development of RCW habitat, and 2) discuss problems we encountered that introduced error and uncertainty into the results. This modeling approach was based on several assumptions: 1) the effects of site preparation persist throughout stand development, 2) survival and growth of current trees are solely determined by the size and number of trees in the previous time step, and 3) tree size variation within a stand is minimal so the quadratic mean diameter (QMD) and mean DBH are approximately equal. Although a number of growth and yield models exist for longleaf pine, most are for stands ≥ 20 years old and application is often restricted to specific site and stand conditions. Additionally, the biology of longleaf pine presents unique challenges for developing models of stand growth at young ages, due to the extended and often variable period of time in the grass stage (Goelz 2001). Consequently, we were liberal in application of existing models, resulting in greater error in our results. However, this exercise demonstrates theoretical scenarios for longleaf pine stand development after site preparation and clearly shows our need for a better understanding of the dynamics of stand development.

4.2.2 Methods

See Section 3.1 for descriptions of the study site, experimental and treatment descriptions.

Data Collection

Seedling survival was monitored in 2005, after two years of growth. In 2006, a sub-sample of 20 seedlings was randomly selected for third year growth measurements. We used digital calipers to measure root collar diameter (RCD) and a height pole to measure height to the terminal bud of all seedlings selected for measurement. Seedlings were determined to be in height growth when the terminal bud reached a height of 15 cm (Boyer 1988, Nelson and others 1985). Because most of the seedlings were in the grass stage, we calculated mean dominant height as the tallest half of surviving trees per plot. Boyer (1983) found that this fraction of grass stage seedlings represented a large number of vigorous seedlings that would likely become dominant and co-dominant canopy trees. Mean survival, RCD, and dominant height are summarized by treatment in Table 4.2.1.

At four additional 10 year old longleaf pine plantations, we randomly selected two 100 m^2 sampling plots to measure tree growth at age 10. Within each sampling plot, we marked each tree with a numbered aluminum tag and recorded RCD, DBH, and total height. The 10 year old plantations were either bedded or not prepared prior to planting, and all plantations were on Leon soils.

Model Selection and Application

We searched the literature for the most appropriate models for our stand and site types. To our knowledge, Brooks and Jack (2006) developed the only model available to project stand growth and development for stands younger than 9 years old. Because models do not exist for the specific conditions of our study sites, we were liberal with model application and describe model assumptions that may be violated in Table 4.2.2. Projections of quadratic mean diameter and basal area were used as a gauge of RCW habitat suitability, assuming that 9.2 m^2/ha basal area of 25 cm DBH longleaf pine trees is an appropriate threshold for good quality foraging stand structure.

Survival--To project survival to age 19, we used a model that projects future number of trees from stand age and current number of trees, developed by Brooks and Jack (2006) (Eq. 1):

$$N_2 = N_1 * Exp\left\{\alpha_1\left(\left(\frac{A_2}{10}\right)^{\alpha_2} - \left(\frac{A_1}{10}\right)^{\alpha_2}\right)\right\} \qquad \text{(Eq. 1)}$$

where N_2 = projected survival in trees per hectare at age A_2, N_1 = current trees per hectare at age A_1, A_1 = stand age at the start of the growth period, A_2 = stand age at the end of the growth period, α_1 = -0.206745, and α_2 = 0.360652.
To extend survival projections from age 19 to age 60, we used a model developed for unthinned longleaf pine plantations by Lohrey and Bailey (1977) (Eq. 2):

$$N_2 = N_1\left\{Sin^2\left[\frac{\pi}{2} + \left(1 - \frac{A_1}{A_2}\right) * \left(\beta_1 + \beta_2 * \sqrt{N_1} + \beta_3 * A_1 + \beta_4 * (A_1)^2\right)\right]\right\} \qquad \text{(Eq. 2)}$$

where β_1 = -2.827365, β_2 = -0.032141, β_3 = 0.221332, and β_4 = -0.004125.

Dominant height--Brooks and Jack (2006) used a modified Chapman-Richards height/age projection function for other southern pines (Pienaar and Shiver 1980) to predict dominant height. Future dominant height is projected from stand age and current dominant height for plantations age 2 to 19, as follows (Eq. 3):

$$DHT_2 = DHT_1\left[\frac{1 - Exp(\lambda_1 * A_2)}{1 - Exp(\lambda_1 * A_1)}\right]^{\lambda_2} \qquad \text{(Eq. 3)}$$

where DHT_2 = projected dominant height at age A_2, DHT_1 = current dominant height at age A_1, λ_1 = -0.07576, and λ_2 = 2.099041.

Basal area--We used a model developed by Brooks and Jack (2006) to project basal area to age 19. This model predicts future basal area from current basal area, current and

future dominant height, and current and future survival for plantations age 2 to 19 (Eq. 4):

$$BA_2 = Exp\{Ln(BA_1) + \delta_1(Ln(DHT_2) - Ln(DHT_1)) + \delta_2(Ln(N_2) - Ln(N_1))\} \qquad \text{(Eq. 4)}$$

where BA_2 = projected basal area at age A_2, BA_1 = projected basal area at age A_1, δ_1 = 1.817699, and δ_2 = 7.398342.
In applying this model, we calculated current basal area from measurements of RCD, with the assumption that basal area calculated from RCD could be used in place of basal area calculated from DBH. However, taper of the tree stem will cause diameter at the root collar to be larger than diameter at breast height, and consequently, basal area projected from RCD would be substantially larger than basal area calculated from DBH.

To rectify this, we followed a number of steps to convert basal area calculated from RCD to an estimated basal area from DBH. First, we converted the basal area projected to age 10 (from Eq. 4) to quadratic mean diameter (QMD), which would represent mean RCD at age 10. Then we used the data we collected from 10 year old plantations and simple linear regression to develop the following relationship between RCD and DBH at age 10 (Eq. 5):

$$DBH = -0.6526 + 0.7405(RCD) \qquad \text{(Eq. 5)}$$

$r^2 = 0.86$; n = 143; SSE = 312.12; $p < 0.0001$

Using this relationship, we predicted DBH at age 10 from the projected RCD and converted this back to basal area. Under the assumption that the relationship between RCD and DBH was independent of age, we projected basal area at age 10 backward to age 3 and forward to age 19 using Equation 4.

The model we selected for projecting basal area past age 19 was developed for a variety of stand ages (11-90), site indices (13.7-29.0 m; base age 50) and densities (3.7-37.9 m^2/ha basal area) in the east gulf region (Farrar 1985) (Eq. 6):

$$BA_2 = \left\{ \frac{\theta_1}{\theta_2} - \left[\frac{\theta_1}{\theta_2} - (BA_1)^{(1-\theta_3)} \right] * \left(\frac{A_2}{A_1} \right)^{(-\theta_2(1-\theta_3))} \right\}^{\left(\frac{1}{1-\theta_3}\right)} \qquad \text{(Eq. 6)}$$

where θ_1 = -1.0007, θ_2 = -5.6643, and θ_3 = 1.3213. This model was designed to predict longleaf pine growth in natural stands with periodic thinning. In this model, basal area is predicted from stand age and current basal area using a modified form of the Chapman-Richards growth function (Pienaar and Turnbull 1973).

Quadratic mean diameter--Projected basal areas were converted to QMD and plotted for each treatment.

4.2.3. Results and Discussion

Both models used to project longleaf pine survival followed a reverse "J" shaped curve, with mortality greatest early in the growth period and slowing down over time (Figure 4.2.1). Previous studies have reported the greatest longleaf pine mortality in the first year after planting (Boyer 1988, Knapp and others 2006), followed by a fairly low mortality rate through age 20 (Wilhite 1976). By age 60, projected survival ranged from 437 to 475 trees per hectare, a level of stocking that would be unusually high for stands managed for RCWs. For example, a uniform stand with 25 cm DBH trees requires only around 270 trees per hectare to maintain 13.8 m^2/ha of basal area. It is likely that managers would periodically harvest to reduce stand density, allowing residual trees more resources for growth. Tree density would therefore be dictated by management activities rather than natural mortality and would not limit RCW habitat development.

Traditional growth models commonly use site index functions to predict dominant height (Farrar 1981, U.S. Forest Service 1976), but are unable to accurately account for changes in site quality caused by site preparation. Boyer (1980; 1983) compared height over age curves of young longleaf pine plantations established on old fields, mechanically prepared cutover forests, and unprepared cutover forests and found that site index curves were affected by site history/preparation as well as site quality. The Brooks and Jack (2006) model (Eq. 3) projected future dominant height from current dominant height rather than site index, thereby allowing us to account for differences in site quality resulting from site preparation.

Projected dominant height at age 19 was quite variable among the treatments, ranging from virtually no height growth on CF and F to over 10 m on CHB (Figure 4.2.2). Projections for some treatments were lower than expected. For example, it is unlikely that dominant height of a 19 year-old stand would remain below 2 m, as projected for CM, CF, HF, and F, unless seedlings never emerged from the grass stage. On sites with intense competition, it is possible that grass stage emergence would not occur without site improvement (i.e. site preparation). However, it is also likely that error was introduced into our projections by applying the Brooks and Jack (2006) model (Eq. 3) to data from grass stage seedlings. Treatments with age 3 mean dominant height > 15 cm (CHB, HB, HM; Table 4.2.1) were likely to have a greater proportion of seedlings out of the grass stage and result in more accurate projections of dominant height. On CHB, in which the majority of seedlings had emerged from the grass stage by age 3, our projection of dominant height at age 19 was similar to the dominant height of 19 year-old longleaf pine reported in a study conducted on Leon sand in northeastern Florida (Wilhite 1976), suggesting that model accuracy may be greatly improved as seedlings emerge from the grass stage.

Basal area and QMD growth projections were very different among the treatments, ranging from 5.3 to 23.7 m^2/ha basal area (Figure 4.2.3) and 9.8 to 21.1 cm QMD (Figure 4.2.4) at age 19. In the Wilhite (1976) study, 20 year-old longleaf pine plantations had a basal area of 14.5 m^2/ha and DBH of approximately 12.7 cm. Prior to planting, those sites were prepared by scarifying the soil several times with an agricultural disk harrow and mechanically removing saw-palmetto (*Serenoa repens* (Bartram) Small). Such site preparations would fall within the range of site preparation intensity used in our study,

and therefore it is not surprising that the values reported by Wilhite (1976) are within the range of projected values for basal area and QMD reported in our study.

When considering RCW habitat suitability, all treatments were projected to reach a basal area of 9.2 m^2/ha by around age 25 (Figure 4.2.3), suggesting that tree diameter will be a more important indicator of when these stands will become good quality foraging habitat. For instance, CHB is projected to reach a basal area of 9.2 m^2/ha around age 11, at which point QMD is only 13.8 cm (Figure 4.2.4). Assuming that stands will first become usable as RCW habitat when QMD reaches 25 cm, our growth projections indicate drastic treatment differences in time to habitat suitability. Three treatments, CHB, HB, and HM, may be expected to reach suitable size for foraging habitat by around age 30, with the fastest growing treatment (CHB) projected to reach 25 cm QMD at around age 25. On the other hand, the slowest growing treatments, F and CF, will not be suitable for RCW habitat until around age 50.

Our results demonstrate theoretical differences in stand development following site preparation, but we acknowledge the uncertainty introduced by such liberal application of existing models (Table 4.2.2). Error in our projections caused by exceeding model limitations was compounded by combining models for long-term extrapolation. Perhaps the most serious problem with modeling stand development of young longleaf pine is the unpredictable growth of grass stage seedlings. Currently, no models are available to translate grass stage measurements (primarily RCD) to projections of sapling/tree measurements (height/DBH). Although it is accepted that grass stage emergence typically occurs when the root collar approaches 2.5 cm (Boyer 1990), emergence at the stand level and subsequent growth patterns are not fully understood and therefore difficult to model. The Brooks and Jack (2006) model (Eq. 4) was developed to project stand growth from a young age, but assumes that seedlings have reached a height of at least 1.4 m (DBH height). Many seedlings in our study were measured in the grass stage, violating that assumption and reducing the reliability of resulting model projections.

In this modeling exercise, we assume that effects of site preparation will last throughout stand development; however, there is evidence that early increases in longleaf pine growth following site preparation do not persist throughout stand development (Boyer 1996). For example, Boyer (1985) studied the effects that timing of release from competition had on short- and long-term longleaf pine growth response by comparing growth following complete hardwood competition control applied at ages 1, 2, 3, 4, and 8, and an unreleased check. At age 10, dominant tree height was greatest on treatment plots released at age 1 and decreased with each subsequent year of release. By age 31, however, dominant height was similar among all released treatments, but remained significantly greater than the unreleased check. It is possible that as stands develop and canopies close, competition from understory species is reduced and growth is more strongly influenced by site productivity and intraspecific competition than by understory competition (Boyer 1983). However, it remains unclear how long the effects of mechanical treatments that change micro-topography (i.e. bedding and mounding) would impact site productivity and tree growth.

An important benefit of increased early growth is a reduction in the length of time that seedlings remain in the grass stage. Longleaf pine seedlings have the ability to persist in the grass stage for over 10 years in unfavorable conditions (Pessin 1944) and in extreme cases may never enter height growth. Emergence from the grass stage is critical to stand establishment, and site preparation treatments may be one way to ensure successful height growth. On sites with extreme competition, improved chances for emergence may justify use of site preparation, regardless of subsequent growth benefits. It is logical that early grass stage emergence should correspond with shorter time to maturity. However, the ability of longleaf pine to make up for early growth deficits (Boyer 1983, Boyer 1985, Boyer 1996) suggests that this may not be the case and highlights our lack of knowledge about the early stages of stand development.

4.2.4. Conclusions

Our model projections demonstrate theoretical differences in stand development following site preparation, but also make clear some problems associated with modeling growth of young longleaf pine. Assuming that stands become suitable foraging habitat when trees $\geq$ 25 cm DBH reach a basal area of 9.2 m^2/ha, we projected that CHB would become habitat 25 years faster than the untreated check. Our results suggest that site preparation may be a useful tool for land managers wishing to shorten the time required to grow longleaf pine plantations into RCW habitat on this site type. However, we acknowledge the uncertainty of our results and intend for this study to raise questions for future research rather than provide concrete management guidelines for landowners.

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Tables

Table 4.2.1. Mean trees per hectare (TPH), root collar diameter (RCD; mm), and dominant height (m) used as starting points for projecting growth. Trees per hectare was calculated from second growing season survival (2005); RCD and dominant height were measurements taken three years after planting (2006).

Treatment	TPH	RCD (mm)	Dominant Height (m)
CB	876	29.1	0.188
CF	819	18.9	0.031
CHB	782	35.8	0.645
CM	788	25.4	0.126
F	812	17.5	0.018
HB	776	34.0	0.400
HF	795	23.6	0.101
HM	777	30.6	0.299

Table 4.2.2. Description of models used to project stand growth for our study. "Variables" represent the variables we used each model to project. "Stand characteristics" and "site description" describe important information about the stands/sites used in model development, and "possible model violations" describes some possible sources of error introduced into our projections.

Model	Variables	Stand characteristics	Site description	Possible model violations
Brooks and Jack (2006)	- Survival - Dominant height - Basal area	- Age 2 to 19 - Stand density 674 to 2322 TPH - Basal area 1.2 to 31.2 m^2/ha	- Well-drained soils - Southwest Georgia	- Seedlings used in model development were ≥ 1.4 m tall (i.e. all were out of the grass stage). Our measurements were primarily seedlings in the grass stage; we calculated basal area from root collar diameter. - Our study sites are poorly drained. Growth may differ based on drainage.
Lohrey and Bailey (1977)	- Survival	- Age 16 to 38 - Planting density from 618 to 6178 TPH -Surviving density from 74 to 3823 TPH - Unthinned plantations	- Site indices (25 years) from 9 to 22 m - Central LA and east TX	- We used this model to project survival to age 50, extrapolating past the maximum age used in model development - The model was developed in a different region than our study.
Farrar (1985a)	- Basal area	- Age 11 to 90 - Basal area from 3.7 to 37.0 m^2/ha - Even-age natural stand - Period thinning	- Site indices (50 years) from 14 to 29 m - Region wide study from east Gulf region	- Model developed in naturally regenerated stands in the east Gulf region. Site and stand conditions are different from our study. - Model developed from stands thinned on 5-year intervals; the author suggests restricting use of this model to short growth periods, not to exceed 30 years.

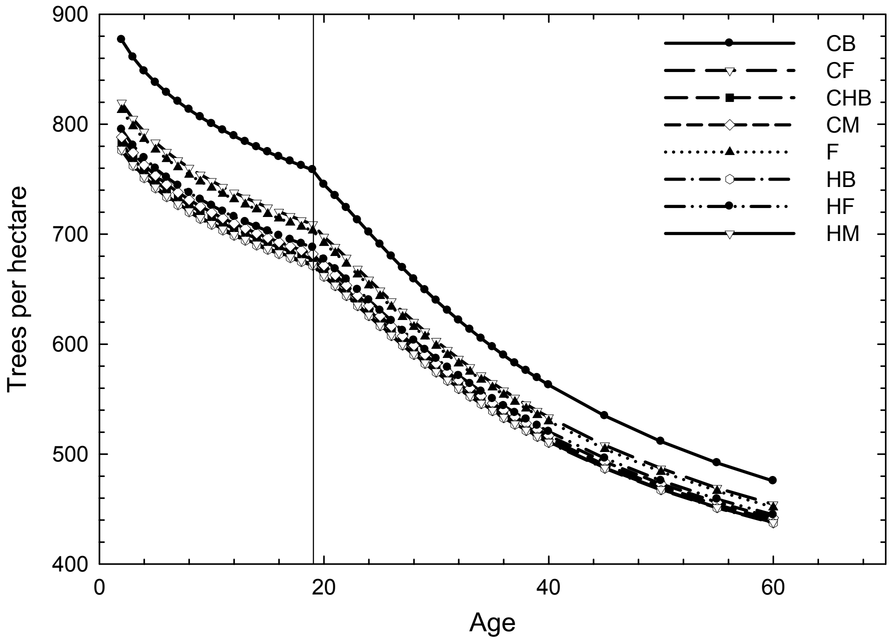

Figure 4.2.1. Trees per hectare projected from age 2 to age 60. Vertical line at age 19 represents a change in model from Brooks and Jack (2006) to Lohrey and Bailey (1977).

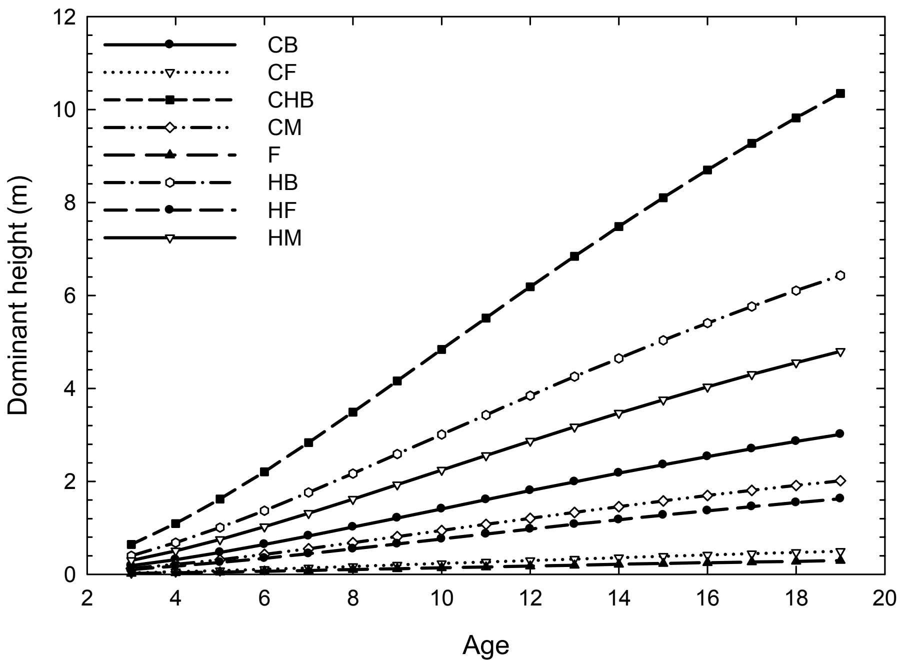

Figure 4.2.2. Dominant height (m) projected for ages 3 to age 19 using the model developed by Brooks and Jack (2006).

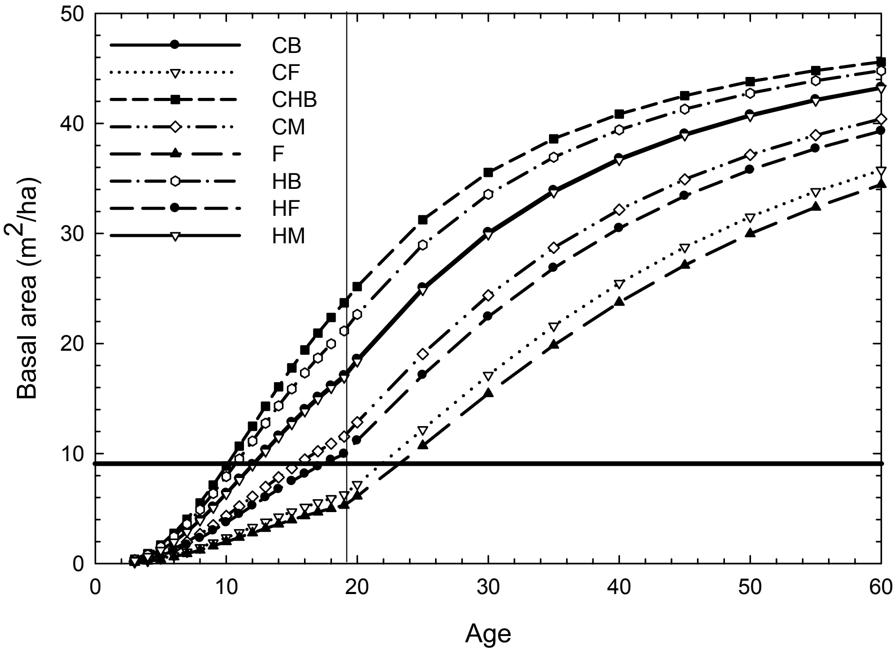

Figure 4.2.3. Basal area (m^2/ha) projected from age 3 to age 60. The vertical line at age 19 represents a change in model from Brooks and Jack (2006) to Farrar (1985). The horizontal line at 9.2 m^2/ha represents the lower basal area limit recommended for good quality RCW habitat.

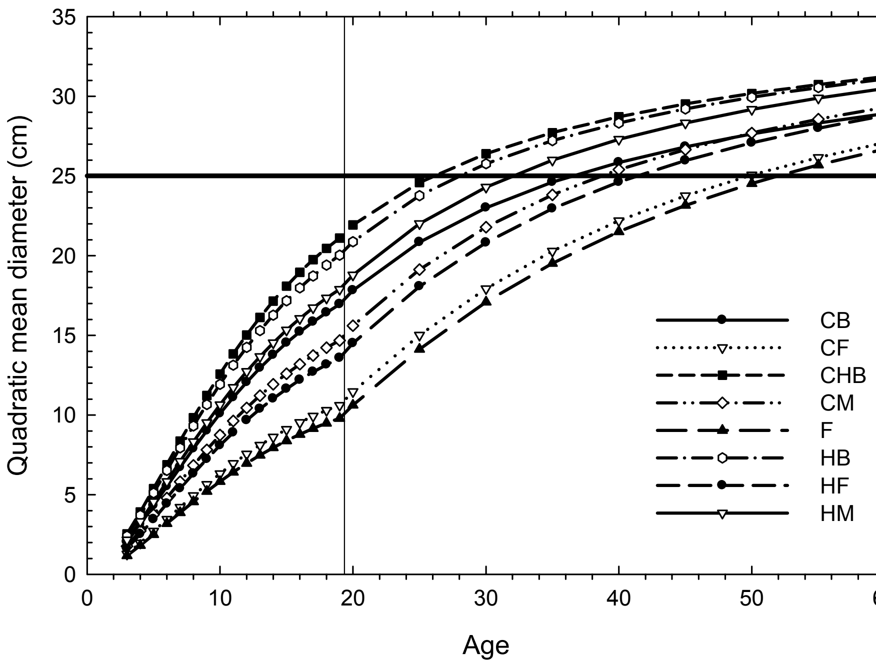

Figure 4.2.4. Quadratic mean diameter (cm) projected from age 3 to age 60. The vertical line at age 19 represents a change in model from Brooks and Jack (2006) to Farrar (1985). The horizontal line at 25 cm represents the lower basal area limit recommended for good quality RCW habitat.

5. Implications for endangered, threatened, at-risk species (TERS) at MCB Camp Lejeune

The primary goal of this project was to strengthen the scientific basis for selecting site preparation methods to restore longleaf pine on somewhat poorly drained sites, while retaining and restoring the diverse ground layer vegetation, a condition associated specifically with high quality habitat for red-cockaded woodpeckers and generally with high quality natural areas. This section discusses the project results first in the context of suitable red-cockaded woodpecker foraging habitat and then with respect to other TERS at Camp Lejeune.

5.1 Plantation management and restoring RCW foraging habitat

The U.S. Fish and Wildlife recovery standard guidelines (U.S. Fish and Wildlife Service 2003) specify criteria for quality RCW nesting and foraging habitat. Although RCWs generally favor older trees in the forest for use as cavity trees (often 80 to 150 years old), stand criteria for good quality foraging habitat may be reached sooner. Stand structure for good quality foraging habitat includes, but is not limited to: (1) at least 45 pines/ha that are > 35 cm in diameter at breast height (DBH), 60 years old, and total at least 4.6 m^2/ha basal area; (2) basal area of all pines ≥ 25 cm DBH is at least 9.2 m^2/ha; and (3) basal area of pines ≤ 25 cm DBH is lower than 2.3 m^2/ha and density below 50 stems/ha. In general, these guidelines describe stands that are dominated by large, old pines and include low densities of smaller pines or hardwoods. The quality of foraging habitat generally improves with tree size, as indicated by the requirement of a minimum number of large (> 35 cm DBH), old (≥ 60 years old) trees. In addition to stand structure, the recovery plan specified that high quality RCW habitat has a ground layer of at least 40% cover of native herbaceous species.

Our study showed that short-term effects on both early pine growth and non-pine vegetation varied among low- to moderate-impact site preparation methods likely to be used on military installations in the longleaf pine range (Section 3.4). A general comparison based on our results of site preparation treatments is given in Table 5.1.1. With respect to herbaceous cover in the ground layer, at the end of three growing seasons all site preparation treatments in this study met the 40% herbaceous ground cover standard. Based on the comparison of plantations and reference longleaf pine vegetation, however, it is evident that the quality of the ground layer declines with plantation development. Plantations had less than 25% herbaceous (graminoids plus forbs) ground cover. When this loss of herbaceous cover occurred and which mechanisms drove the change are matters for speculation. Shade, belowground competition, and litter accumulation have been associated with the changing herbaceous diversity in developing longleaf pine forests (Harrington 2006). There are no long-term studies that combine site preparation experiments with prescribed burning on poorly drained sites; however, selected results from several studies are informative.

The Competition Omission Monitoring Project (COMP) was initiated in 1984 to evaluate the effects of four treatments for the early control of competition in loblolly pine

plantations: (1) herbaceous competition control, (2) woody competition control, (3) total competition control, or (4) no controls (Miller et al. 2003). Competition control was achieved by herbicide applications that varied among sites, but were tailored to the site specific conditions. Study sites were distributed across four physiographic provinces in the southeastern U.S. The two study sites with shrub-dominated woody competition, including a poorly drained flatwood site at Pembroke, GA, are most comparable to the experimental site in our study. The COMP study differed from our study in two significant ways: (1) treatments were applied for 3-4 years and then ceased and (2) there was no prescribed fire on these sites. Approximate results for the no competition control and the woody competition control treatments are represented in Figure 5.1.1. Early patterns were similar to our study: little change or slight increases in herbaceous cover, and reduction of woody vegetation by herbicides, but continued growth with no competition control. Beginning at age 6-8 years, herbaceous cover declined to less than half of the cover at the time of planting (~75% to 17% and 35% herbaceous cover with no competition control and woody control plots respectively) and lower than both the acceptable RCW habitat standard and the mean herbaceous cover in reference longleaf pine plots on MCBCL (43%; Section 4.1). Following this pattern, without fire the herbaceous cover on Camp Lejeune flatwoods would fall below the habitat standard by age 15, and perhaps as early as 10 years (Figure 5.1.1). Miller et al. (2003) reported that rapid herbaceous decline began when the woody canopy (pine and shrubs) reached about 60%, implicating competition with woody vegetation as the cause. In addition to possible competition for light, nutrients and water, herbaceous vegetation may be limited by the accumulation of litter (Miller et al. 2003) or an organic forest floor (Hiers et al. 2006). Ground layer changes with longleaf pine plantation initiation and development are summarized in Figure 5.1.2.

Though many of the plantation sites sampled in our project had been thinned at least once, the herbaceous component of the ground layer had not yet responded substantially (Section 4.1). It is possible that with further thinning the sun-loving groundcover herbs and grasses could increase (Kush et al. 2004). For thinning and prescribed burning to enhance the herbaceous component, there would have to be residual populations of desirable species, a persistent seed bank, and/or nearby propagule sources (Walker and Silletti 2006). Cohen (1998) showed that the seed bank in similar sites is not completely depleted in young plantations, but the abundance of "ecologically conservative" species is low. It seems unlikely that relying on the seedbank to recover the dominant bunchgrasses and diverse forb component will be a very effective strategy for groundcover restoration. Further, the success of local seed sources will be limited by natural dispersal mechanisms and the availability of suitable "safe sites" for germination, presumably bare mineral soil rather than a forest floor carpeted in thick pine straw (Glitzenstein et al. 2001).

An accumulation of organic litter during plantation development was avoided or reduced by prescribed burning during the development of naturally regenerated longleaf pine stands in Alabama (Kush et al. 1999). The dominant shrub in these Alabama sites was *Ilex glabra* (inkberry) also present in the MCBCL sites, suggesting site similarities in spite of geographic distance between them. In unburned Alabama plots the heavy litter

layer and midstory accumulation is credited with the loss of the herbaceous component, while burning reduced forest floor organic matter by 66% compared to unburned plots. The negative association of forest floor depth to herbaceous layer vigor (Hiers et al. 2006) and the apparent effectiveness of fire for removing forest floor (Kush et al. 1999) underscore the important role of fire in determining ground layer condition in plantations. However, the effectiveness of prescribed burning in young plantations may be compromised by the site preparation techniques that disrupt fuel distribution or potentially enhanced by techniques the favorably redistribute woody fuel, as shown in this project (Section 3.5). With this awareness, fire managers should be able to modify fire prescriptions in order to produce desired fire behavior.

At some point during plantation development, it is likely that the canopy will compete effectively either above- or below-ground with the herb layer (Harrington 2006). The rate at which this will occur almost certainly varies with site quality and is likely to be shortened by site preparation treatments that maximize pine growth rates (Section 4.2). Continued monitoring of the experimental plots could yield site-specific answers to important management questions including the following: Is there a threshold of canopy cover or basal area that triggers rapid changes in the ground layer? If so, how does it vary with site quality?

5.2. Potential impacts of site preparation on threatened, endangered, and at-risk species (TERS): general considerations

Table 5.1.2 lists endangered, threatened, and North Carolina plant species of concern that have been located, some provisionally, on Camp Lejeune (Data source: North Carolina Natural Heritage Program, NC Department of Environment and Natural Resources). This list includes only species likely to occur on wet sites historically dominated by longleaf pine and maintained by frequent burning. Of the 35 species on this list, 4 were confirmed present in experimental plots and 7 additional species possibly occurred there. Characteristics of both the individual plant species of concern and of the management disturbance will influence the likelihood of adverse impacts over time. Because this research project was not designed to sample and detect impacts on rare species, we only speculate on the potential impacts.

Most plant populations, both common and rare species, are patchily distributed. The site preparation disturbances used at Camp Lejeune are selected to disturb only a portion of the surface area; intensive treatments that completely disrupt the soil surface, as a matter of policy, are not selected. Thus, the direct impacts of a treatment depend on the coincidence of management disturbance patches with plant population patches. The greater the proportion of ground disturbance, the greater is the likelihood of losing small populations. In our study the broadcast herbicide application potentially affected 100% of the community while bedding and mounding disturbed about 50 and 25% respectively. Indeed, herbicide treatments were the most effective in reducing overall cover in this study (Section 3.4).

Large populations may lose individuals and be expected to recover; however, small populations, as are characteristic of many rare species, may be eliminated by chance. The lack of a local seed source will preclude recovery. Species with local sources of seeds within dispersal range or with persistent seed banks may re-establish from seed. Seeds recorded in a seed bank study conducted in the outer coastal plain of North Carolina included a variety of weedy species, but also small graminoids that were characteristic of the natural community (Cohen 1998).

All the state species of concern that are present or possibly present in the study sites are small seeded species that occur in patches, but generally in multiple patches within a stand. Surviving patchy disturbances are likely; the effects of canopy closure are not certain. The most effective strategy for managing federally protected plant species is to survey sites prior to ground-disturbing treatments, and to avoid any known populations. No Federally listed species are present in the sites targeted for forest regeneration.

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Tables and Figures

Table 5.1.1. Summarized effects of site preparation treatments.

Response	Treatment			
	Chop/Chop-Flat	**Bed/ Mound**[1]	**Herbicide (Pre-plant shrub control)**	**Bed + Herbicide + Chop**
Seedling survival	No differences	No differences	No differences	No differences
Early growth (rcd)	Lowest	Med/high	Med/high	Highest
Competition control for seedlings	Low, 1 season	Medium, 1-2 seasons	High, ≥ 3 seasons	High, ≥ 3 seasons
Total ground layer cover (REF[2] : >100%)	(~80%)Lower than reference site mean	1-2 seasons	Reduced ≥ 3 seasons	Reduced ≥ 3 seasons
Woody species cover (REF: 70%)	(~50%) Lower than reference site mean	Reduced 2 seasons	Reduced ≥ 3 seasons	Reduced ≥ 3 seasons
Herbaceous cover (REF: 43%)	(~30-40%) Lower to nearly equal to reference site mean	No change	Initial decrease, but post-fire increase at 3 seasons	Similar to herbicide effects
Spp/m2 (REF:~10/m^2)	Similar to reference sites mean	1 season reduction in plot mean	Reduced ≥ 3 seasons	Similar to chopped and flat treatments
Fire behavior	Fewest unburned patches, highest temperatures	More unburned patches, lowest temperatures with beds, mounds intermediate	No clear effect on fire behavior	Similar to other bedded treatments
Residual fuel	Lowest	High (related to discontinuous fuel bed)	High (related to poor fuel arrangement, i.e. standing dead shrubs)	Highest – additive effect of fuel continuity (bed) and fuel arrangement (chop)
Time to suitable basal area for RCW foraging	~ 22-24 years	~12-14 years	- beds/mounds 7years; + beds/mounds 10-11 years	~10 years
Time to suitable diameter for RCW foraging	> 50 years	36-38 years	- beds/mounds 42 years + beds/mounds 28-32 years	~25 years

1 Described in comparison to F or CF treatments.
2 REF = The mean of reference plots (Section 5).

Table 5.2.1. Plant species tracked by the NC State Heritage Program and found on or near Camp Lejeune. These species may occur on wet sites historically dominated by longleaf pine. X indicates species presence confirmed in experimental plots; + indicates possible occurrence. Federally protected species are indicated in bold-face type. (Date source: NC Natural Heritage Program.)

Scientific Name	**Global rank[1]**	**State rank**	**NC State rank[2]**	**Presence**
Agalinis aphylla	G3-G4	S3	SR-P	
Agalinis virgata	G3-G4	S3	SR-P	
Asclepias pedicellata	G4	S2	SR-P	
Calopogon multiflorus	G2-G3	S1	E	
Carex verrucosa	G3G4	S2	SR-P	+
Circium lecontei	G2G3	S2	SR-P	
Cladium mariscoides	G5	S2	SR-O	
Cyperus lecontei	G4?	S2	SR-P	+
Dichanthelium hirstii	G1	S1	E	
D. sp.9= Panicum cryptanthum	G2G3	S2	SR-L	
Dionaea muscipula	G3	S3	SR-L,S	X
Lachnocaulon minus	G3G4	S2	SR-P	+
Lindera melissafolia	**G1**	**S1**	**E**	**+**
Litsea aestivalis	G3	S2	ST-T	
Lobelia boykinii	G2G3	S2	T	+
Lophiola aurea	G4	S2	E	
Ludwigia linifolia	G4	S2	SR-P	
Lysimachia asperulifolia	**G3**	**S3**	**E**	
Muhlenbergia torreyana	G3	S2	E	
Panicum tenerum	G4	S3	SR-P	
Polygala hookeri	G3	S2	SR-T	+
Rhexia aristosa	G3	S3	T	
R. cubensis	G4G5	S3	SR-P	
Rhynchospora breviseta	G3G4	S2	SR-P	X
R .harperi	G4?	S2	SR-P	
R. oligantha	G4	S2S3	SR-P	+
R. scirpoides	G4	S2	SR-O	
R. tracyi	G4	S2	SR-P	
Sagittaria graminea var. chapmanii	G5T3?	S1	SR-P	
Scirpus pendulus	G5	S1	SR-O	
Scleria georgiana	G4	S2	SR-P	
S.reticularis	G4	S2	SR-O	
S.verticillata	G5	S2	SR-P	
Solidago pulchra	G3	S3	SR-L	X
Sphagnum fitzgeraldii	G2G3	S2S2	SR-T	
Spiranthes laciniata	G4G5	S2	SR-P	
Xyris brevifolia	G4G5	S2	SR-P	X

[1]Global and State Ranks used by State Heritage Programs and Nature Serve; terms defined at www.NatureServe.org.

[2]State ranks are assigned by the Plant Conservation Program (NC Department of Agriculture) and the Natural Heritage program (NC Department of Environment and Natural Resources). Endangered, Threatened, and Special Concern species are protected by state law (Plant Protection and Conservation Act, 1979). Candidate and Significantly Rare designations indicate rarity and the need for population monitoring and conservation action. E, endangered; T, threatened; SC, special concern; C, candidate; SR, significantly rare; P-proposed; -L, limited range; -T, rare throughout range; -P, at the edge of its range; -O, sporadic range.

Figure 5.1.1. Change in cover of pines, herbaceous species, and woody species through time. Graphs reproduce a facsimile of results reported in Miller et al. 2003 (SJAF 221-236) for loblolly pine plantations established on shrubby sites using herbicides to control woody competition or no control of competition.

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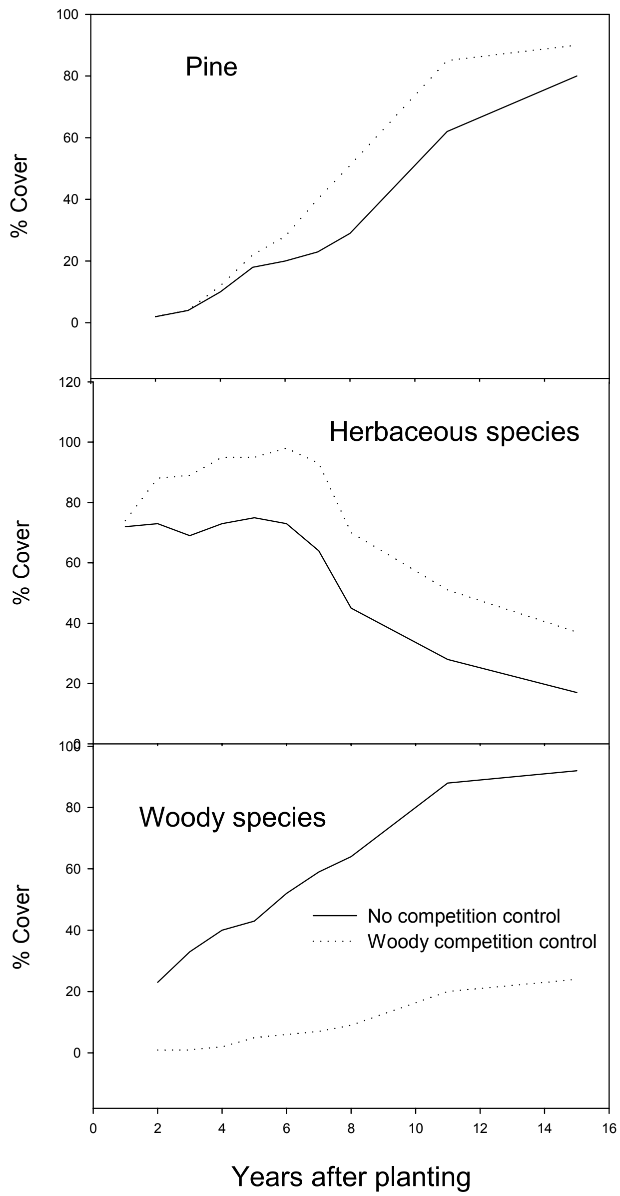

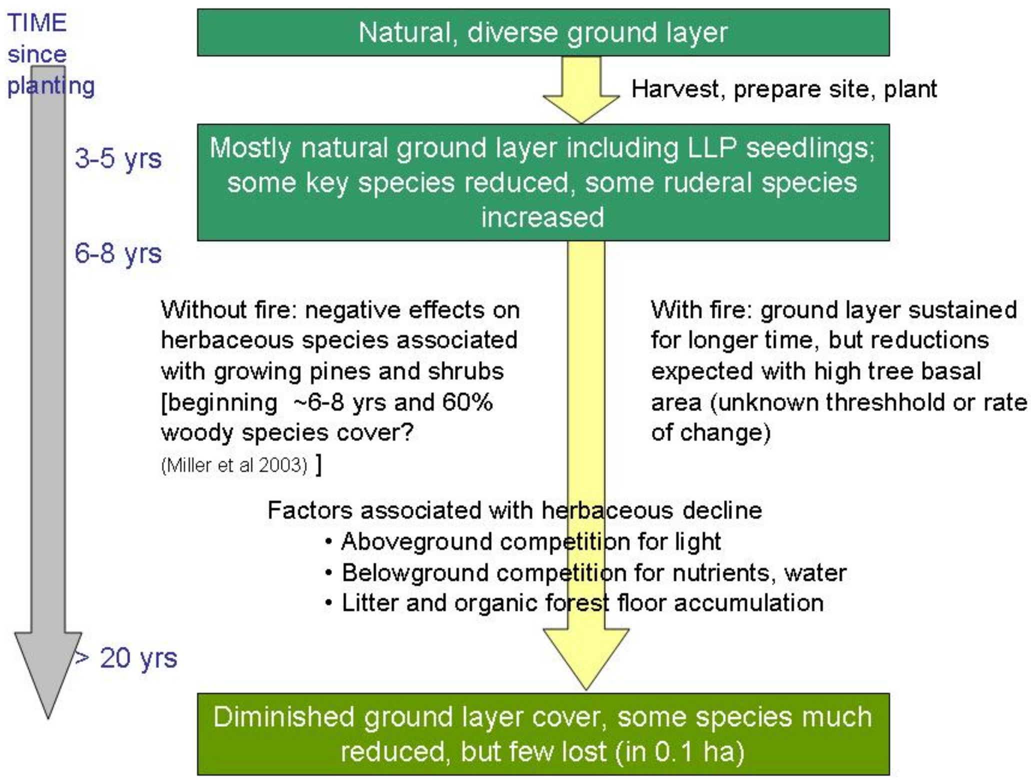

Figure 5.1.2. Changes in the ground layer vegetation following longleaf pine plantation establishment on a site with a characteristic native ground cover at the time of site preparation. There are few short-term direct effects of low- to moderate-intensity methods (as used in this project) on the herbaceous ground cover. Plantation development is associated with much reduced cover, but few species are lost. Site preparation choice may affect the rate of decline by accelerating the rate tree growth or changing the behavior of prescribed fire.

6. Monitoring Experimental Plots

Vegetation in the experimental plots will continue to change beyond the time allotted for the original project. The patterns and rates of change in both the ground layer condition and the development of the longleaf pine stand are needed to refine management strategies for restoration. Monitoring all vegetation strata is recommended. It is assumed that the experimental plots will be managed as directed in the Integrated Natural Resources Management Plan for Camp Lejeune, with prescribed burning and silvicultural thinning. Both of these practices are likely to affect pine stand development and ground layer condition. Permanent plot locations are provided in a GIS data layer provided to managers at MCBCL. Maps and treatment assignments are given in Section x.x of this report.

6.1 Longleaf pines

6.1.1 Objectives

Document growth and survival of planted pines, estimate basal area and density of the pine stand, and evaluate effects of initial site preparation on longleaf pine stand development through the first silvicultural thinning. Monitor change after the first thinning to evaluate the effects of thinning on the residual tree growth.

6.1.2 Field methods

To monitor survival and growth of individual trees, 30 seedlings/saplings in each experimental plot will be randomly selected and marked for repeated observations. Trees heights will be recorded. When trees are taller than 1.5 m, diameter breast height (dbh; 1.4 m) will be recorded. Status (dead, alive) will be recorded and evidence for causes of any mortality will be documented.

As an indicator of environmental change with the developing tree canopy, the ground layer light conditions will be assessed using digital camera technology (Wang et al. 2000, Battaglia et al. 2003).

6.1.3 Schedule

Measure stand development in year 6 (2009) and at 5-year intervals thereafter, up until the first thinning. The time of thinning will be determined according to standard timber management protocols. After thinning, another 30 trees will be selected for repeated measures of growth.

6.2 Ground layer vegetation

6.2.1 Objective

Document the composition and structure of the ground layer vegetation (<1 m tall) and woody vegetation >1 m tall, but less than 2 cm dbh (shrub layer) through early longleaf pine stand development and an initial silvicultural thinning.

6.2.2 Field methods

The general approach is to re-measure permanently marked vegetation subplots that were sampled throughout the experiment. Re-sampling permanent plots reduces the number of plots needed to document statistically significant changes in vegetation. Standards for monumenting permanent plots will be determined in consultation with the natural resources staff at Camp Lejeune.

Original measurement protocols used throughout the experiment (pre-treatment through the third year after planting) will be used to monitor vegetation < 1 m tall. Briefly, measurements include 10 1-m2 subplots to be sampled per treatment plot. Abundance will be estimated by aerial cover recorded as NCVS cover classes (Peet et al. 1998) and by plant groups: grasses, forbs, ferns, vines, and shrubs.   Complete species lists will be made for each subplot.

Woody vegetation > 1-m tall, but less than 2 cm dbh (the shrub layer), will be assessed in 4-m2 plots. All stems will be counted and recorded by species.

6.3.3 Schedule

The time after a fire strongly affects the cover and structure of ground layer vegetation. We recommend that vegetation be re-measured at the end of a growing season following management prescribed burning. Current management typically includes prescribed burning on a 3 year interval; because vegetation is likely changing rapidly during early stand development, we recommend vegetation assessments after each burn during the first 10 years. Thereafter, measure vegetation subplots on a 5-year interval, coinciding with pine measurements.

6.3 Data management and reporting

Data should be summarized and archived in a format and location readily available for use by local managers, as well as by managers of other sites and researchers. The data should be summarized periodically, interpreted in the context of longleaf pine ecosystem restoration, and reported to professional meetings (e.g., Society for Restoration Ecologys, Natural Areas Association, and Society for American Foresters).

6.4 Estimated monitoring costs

Monitoring will require personnel for field data collection and permanent plot maintenance, and for data processing and analysis, and reporting. Costs associated with travel must be included if monitoring personnel are not local employees. Equipment and supply costs will be minimal. The most significant costs are in personnel.

Field sampling can be accomplished with 3 technicians supervised by a professional (forester, biologist, or plant ecologist). We estimate that such a field crew could complete sampling of all vegetation strata in about 6 weeks: 8 treatments x 6 complete blocks= 48 plots; each 2-person teams can sample 1 plot per day, for a total of 24 field days; allowing for bad weather and other circumstances we assume 4 full days per week, giving 6 weeks of field work Four weeks should be allowed for data processing and reporting.

Salary Cost estimate per sample year

Field professional @ $ 720/wk x 6 weeks	$4,320.00
Technicians 3 @ $450/wk x 6 weeks	$8,100.00
Analyst @ $1240/wk x 4 weeks	$4,960.00
Total per sampling event	$17,380.00

Literature Cited

Battaglia, M.M., R. J. Mitchell, P.P. Mou, and S.D. Pecot. 2003. Light transmittance estimates in a longleaf pine woodland. Forest Science 49:752-762.

Peet, R.K., T.R. Wentworth and P.S. White. 1998. A flexible, multipurpose method for recording vegetation composition and structure. Castanea 63:262-274.

Wang, G.G., J. Su, and J.R. Wang. 2000. Height growth of planted black spruce seedlings in response to interspecific vegetation competition: a comparison on four competition measures at two measuring positions. Canadian Journal of Forest Research 30: 573-579.

7. Conclusion: Objectives, Accomplishments, Unresolved issues

7.1. Question 1: What are the effects of selected site preparation methods on ground layer vegetation and on longleaf pine establishment and early growth?

Objective 1 --Quantify plant species abundance and plant community diversity in treatment areas prior to site preparation and planting, and at 1, 2, and 3 years after planting. *Objective 1a* -- Describe effects of site preparation treatments on prescribed fire behavior. *Objective 2*--Quantify seedling survivorship at 1 and 2 years after planting. *Objective 3*-- Quantify LLP seedling growth and emergence from the grass stage at 3 years after planting.

The project accomplished Objectives 1-3 as documented in Section 3 of this report. As expected, results indicated significant benefits from bedding, mounding, and herbicide treatments to early longleaf pine seedling growth, although not to seedling survival. These three actions all reduced ground layer cover in the first year, but only herbicide treatments produced changes that were detectable after the third growing season. The herbicide treatment reduced both shrub abundance and diversity at small spatial scales, but at the plot level no species was eliminated. This study was the first forestry use of herbicides at Camp Lejeune, and results suggest that herbicides may be very useful for achieving specific management objectives. Except for dominant shrub species in herbicide treated plots, the ground layer condition was not different from flat planted plots, the most benign approach to plantation establishment.

This study provides the first report of prescribed fire behavior being altered by site preparation. Although the data were "messy," the results suggest that bedding can reduce the amount of area burned and result in lower average fire temperatures. Chopping, as reported elsewhere, did appear to produce an easily burned fuel bed that produced on average the highest maximum temperatures in this study. It is likely that fire managers could safely achieve burn objectives even with the interruptions caused by bedding, but it will be necessary to adjust burn prescriptions to do so. If prescribed fires are not effectively controlling shrub abundance or regularly removing litter, the loss of herbaceous ground cover will be accelerated.

The questions about re the short term effects of low- to moderate-intensity site preparation methods on poorly drained sites are substantially resolved. The magnitude of ground layer vegetation responses should be expected to vary as a results of uncontrollable factors such as extreme climatic trends (e.g., prolonged droughts) or weather events (e.g., hurricanes) that affect the starting condition (vigor) of affected vegetation, but relative changes among treatments are expected to be robust.

7.2. Question 2: What are the persistent effects of past plantation establishment on the structure and composition of the ground layer vegetation on sites that historically supported longleaf pine or a pine mixture including longleaf pine?

Objective 4--Compare vegetation in undisturbed longleaf pine stands with vegetation in plantations, at least 18 years old, on comparable sites. *Objective 5*—Develop conceptual

models that describe how past plantation establishment and other silvicultural practices affect current vegetation.

The comparison of plantations with reference longleaf pine sites clearly showed differences in both the canopy and ground layer vegetation. There were significant differences in species density at scales up to 100 m^2, although species richness in 0.1 ha samples were not different, indicating that most species could be found in established plantations (≥20 years old). Though this may be reassuring, the loss of characteristic species like *Aristida stricta* and *Gaylussacia dumosa* is of concern. The former produces fine fuels critical to sustaining surface fires and the latter is representative of a group of shallowly rooted small shrubs that are important for wildlife. Both of these species were present in the short-term, but are apparently especially sensitive to changes during plantation development. Monitoring these two species, in particular, may help establish thresholds for canopy density or cover that trigger ground cover decline.

Unresolved issue

Objective 5 was not completely accomplished. The stand management data bases were not adequate to unambiguously trace individual stand management, nor were management practices on the installation sufficiently variable to describe a range of stand management histories. We were able to identify consistent differences between plantations and reference vegetation, and those differences do provide a starting point for developing restoration strategies or planning experiments to clarify mechanisms of vegetation change. The mechanisms that drive ground layer changes through plantation development are not well-understood. Most of the previous studies related to longleaf pine community dynamics have been conducted in well-drained, loamy soils. The dominance of shrubs and abundance of soil moisture on poorly drained sites likely will produce unique patterns and higher rates of change than elsewhere. A better understanding of the mechanisms that drive vegetation change is critical for identifying management strategies to prevent species loss, as well as for restoring plantations that have lost ground layer diversity and structure.

7.3. Recommendation for future study

As noted above, an understanding of the mechanisms that drive ground layer change through plantation development would provide a strong foundation for identifying effective strategies to manage regenerating forests or forest patches, and to efficiently restore the large areas of pine plantations that currently do not meet standards for red-cockaded woodpecker habitat.

Appendices

Appendix GL1. List of species encountered in experimental study plots. Functional groups assigned for selected analyses are shown. Taxonomy follows Kartesz 1999.

Appendix GL2. Species recorded in 2006 ranked by frequency of occurrence in all quadrats sampled (n = 480).

Appendix GL3. Means and standard errors of total vegetation A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

Appendix GL4. Means and standard errors of herbaceous A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

Appendix GL5. Means and standard errors of total woody A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

Appendix GL6. Means and standard errors of large graminoid A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

Appendix GL7. Means and standard errors of small graminoid A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

Appendix GL8. Means and standard errors of forb A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

Appendix GL9. Means and standard errors of fern A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

Appendix GL10. Means and standard errors of shrub A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

Appendix GL11. Means and standard errors of vine A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

Appendix GL12. Means and standard errors of total vegetation richness at each scale in A) 2004, B) 2005, C) 2006, and D) all years

Appendix GL13. Means and standard errors of forb richness across all years at each scale

Appendix GL14. Means and standard errors of shrub richness across all years at each scale

Appendix GL15. Abundance (% cover) of each species by treatment (A) 2004, (B) 2005, and (C) 2006.

Appendix PL1. Summary of soil chemistry, soil texture, and tree density and basal area for reference and plantation plots described in Section 4.1.

Appendix 1. Technical publications and presentations.

Technical Publications and Presentations

Publications

Cohen, S. and J. Walker. 2005. Early longleaf pine seedling survivorship on hydric soils. Proc. 13th Biennial Southern Silvicultural Research Conference. February 28 – March 4. Memphis, TN.

Knapp, B.O. and J.L. Walker. 2009. Using existing growth models to predict RCW habitat development following site preparation: pitfalls of the process and potential growth response. Proceedings of the 15th Biennial Southern Silvicultural Research Conference. November 17-20, 2008. Hot Springs, AR [*submitted*].

Knapp, B.O., G.G. Wang, and J.L. Walker. 2008. Relating the survival and growth of planted longleaf pine seedlings to microsite conditions altered by site preparation treatments. Forest Ecology and Management 225(11): 3768-3777.

Knapp, B.O., G.G. Wang, and J.L. Walker. Artificially regenerating longleaf pine on wet sites: preliminary analysis of effects of site preparation treatments on early survival and growth. Proceedings of the 14th Biennial Southern Silvicultural Research Conference. February 26-March 1, 2007. Athens, GA. [*In press*].

Knapp, B.O., G.G. Wang, J.L. Walker, and S. Cohen. 2006. Effects of site preparation treatments on early growth and survival of planted longleaf pine *(Pinus palustris* Mill.) seedlings in North Carolina. Forest Ecology and Management 223(1-3): 122-128.

Knapp, B.O., G.G. Wang, and J.L. Walker. 2004. Effects of site preparation on the first year growth of planted longleaf pine seedlings. Proceedings of Society of American Foresters and Canadian Institute of Forestry 2004 Joint Annual General Meeting and Convention. October 2-4. Edmonton, Alberta, Canada.

Walker, J.L., Silletti, A.M., Cohen, S., 2007. Composition and structure of managed pine stands compared to reference longleaf pine sites on Camp Lejeune, NC. Proc. 14th Biennial Southern Silvicultural Research Conference. Athens, GA.

Manuscripts in preparation for publication

Cohen, S., S. Zarnoch, and J. Walker. Initial effects of longleaf pine flatwoods management on soil nutrients. Being revised according to reviewers' comments for Forest Ecology and Management.

Walker, J.L., B.O. Knapp, A.S. Silletti, S. Cohen. Ground layer vegetation responses to moderate site preparation methods on North Carolina flatwoods sites. In preparation for Forest Ecology and Management.

Walker, J.L. Site preparation treatments in wet flatwoods sites affect prescribed fire behavior in young plantations. In preparation for Southern Journal of Applied Forestry.

Presentations

Oral

Walker, J.L., Silletti, A.M., Cohen, S., 2007. Composition and structure of managed pine stands compared to reference longleaf pine sites on Camp Lejeune, NC. Proc. 14th Biennial Southern Silvicultural Research Conference. Athens, GA.

Knapp, B.O., J.L. Walker, S. Cohen, and A.M. Silletti. 2007. Early effects of site preparation on the native ground layer vegetation of a hydric soil in North Carolina, USA. 2007 Ecological Society of America/Society for Ecological Restoration Joint Meeting. August 4-11, 2007. San Jose, CA.

Knapp, B.O., G.G. Wang, and J.L. Walker. 2007. Artificially regenerating longleaf pine on wet sites: preliminary analysis of effects of site preparation treatments on early survival and growth. 14th Biennial Southern Silvicultural Research Conference. February 26-March 1. Athens, GA.

Knapp, B.O., G.G. Wang, and J.L. Walker. 2006. Effects of site preparation treatments on microsite conditions in relation to growth and survival of planted longleaf pine seedlings in North Carolina. ESA 91st Annual Meeting. August 6-11. Memphis, TN.

Posters

2008. The Partners in Environmental Technology Technical Symposium and Workshop. December 4-6, 2007. Washington, DC.

Knapp, B.O. and J.L. Walker. 2008. Using existing growth models to predict RCW habitat development following site preparation: pitfalls of the process and potential growth response. 15th Biennial Southern Silvicultural Research Conference. November 17-20, 2008. Hot Springs, AR.

Walker, J.L., et al. 2007. IUFRO workshop. Seoul, Korea

Knapp, B.O., J.L. Walker, S. Cohen, and A.M. Silletti. 2007. Plantation management effects on ground layer vegetation: short-term effects diminish but long-term differences are evident. The Partners in Environmental Technology Technical Symposium and Workshop. December 4-6, 2007. Washington, DC.

2006. The Partners in Environmental Technology Technical Symposium and Workshop. December, 2006. Washington, DC.Partners Workshop

Cohen, S., J.L. Walker, and B.O. Knapp. 2005. Restoring longleaf pine on hydric soils: early effects on soil chemistry and seedling survivorship. Soil Science Society of America International Meeting. November 6-10, 2005. Salt Lake City, Utah.

Knapp, B.O., G.G. Wang, and J.L. Walker. 2005. Early survival and growth of planted longleaf pine seedlings in relation to light, soil moisture and soil temperature. Proc. 13th Biennial Southern Silvicultural Conference. February 28-March 4. Memphis, TN.

Cohen, S. and Joan Walker. 2005. Restoring longleaf pine on hydric soils: early effects on soil chemistry and seedling survivorship. Proc. 13th Biennial Southern Silvicultural Conference. February 28 – March 4. Memphis, TN.

Cohen, S. and Joan Walker. 2005. Restoring longleaf pine on hydric soils: early effects on soil chemistry and seedling survivorship. SERDP-ESTCP Partners in Environmental Technology Workshop, Nov. 29- Dec. 1, 2005. Washington, DC.

Knapp, B.O., G.G. Wang, and J.L. Walker. 2004. Effects of site preparation on the first year growth of planted longleaf pine seedlings. Society of American Foresters and Canadian Institute of Forestry Joint Annual General Meeting and Convention. October 2-4. Edmonton, Alberta, Canada.

Thesis

Knapp, B.O. 2005. Effect of site preparation treatments on first-year survival and growth of planted longleaf pine (*Pinus palustris*) seedlings. MS Thesis. Clemson University, Clemson, SC. 110 p.

Appendices

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Appendix 1. Technical publications and presentations.

Appendix GL1. Species List with functional/growth form group assignments.

SECTION	**FAMILY**	***Genus species***	**common name**	**Group**	**SYMBOL**
PTERIDOPHYTES (FERNS AND FERN ALLIES)					
	BLECHNACEAE	*Woodwardia areolata*	netted chainfern	fern/herb	wooare
		Woodwardia virginica	Virginia chainfern	fern/herb	woovir
	DENNSTAEDTIACEAE	*Pteridium aquilinum*	western brackenfern	fern/herb	ptraqu
	OSMUNDACEAE	*Osmunda cinnamomea*	cinnamon fern	fern/herb	osmcin
GYMNOSPERMS					
	PINACEAE	*Pinus elliottii*	slash pine	woody/woody	pinell
		Pinus palustris	longleaf pine	woody/woody	pinpal
		Pinus serotina	pond pine	woody/woody	pinser
		Pinus spp.	pine	woody/woody	pinsp
		Pinus taeda	loblolly pine	woody/woody	pintae
ANGIOSPERMS DICOTS					
	ACERACEAE	*Acer rubrum*	red maple	woody/woody	acerub
	ANACARDIACEAE	*Rhus copallina*	winged sumac	woody/woody	rhucop
	AQUIFOLIACEAE	*Ilex coriacea*	large gallberry	woody/woody	ilecor
		Ilex glabra	inkberry	woody/woody	ilegla
		Ilex myrtifolia	myrtle dahoon	woody/woody	ilemyr
		Ilex opaca	American holly	woody/woody	ileopa

SECTION	FAMILY	Genus species	common name	Group	SYMBOL
ANGIOSPERMS DICOTS	ASTERACEAE	*Ambrosia artemisiifolia*	annual ragweed	forb/herb	ambart
		Aster spp.	aster	forb/herb	astsp.
		Carphephorus odoratissimus	vanilla leaf	forb/herb	carodo
		Carphephorus spp.	chaffhead	forb/herb	carsp.
		Carphephorus tomentosus	woolly chaffhead	forb/herb	cartom
		Conyza canadensis var. pusilla	Canadian horseweed	forb/herb	concan
		Erechtites hieracifolia	American burnweed	forb/herb	erehie
		Erigeron spp.	fleabane	forb/herb	erisp.
		Eupatorium album	white thoroughwort	forb/herb	eupalb
		Eupatorium capillifolium	dogfennel	forb/herb	eupcap
		Eupatorium leucolepis	justiceweed	forb/herb	eupleu
		Eupatorium mohrii	Mohr's thoroughwort	forb/herb	eupmoh
		Eupatorium pilosum	rough boneset	forb/herb	euppil
		Eupatorium rotundifolium	roundleaf thoroughwort	forb/herb	euprot
		Eupatorium spp.	thoroughwort	forb/herb	eupsp.
		Eurybia paludosa	southern swamp aster	forb/herb	eurpal
		Euthamia caroliniana	slender goldentop	forb/herb	eutcar
		Ionactis linariifolius	flatleaf whitetop aster	forb/herb	ionact
		Liatris pilosa	shaggy blazing star	forb/herb	liapil
		Liatris pilosa var. pilosa	shaggy blazing star	forb/herb	liapil v. pil
		Pityopsis graminifolia	narrowleaf silkgrass	forb/herb	pitgra

SECTION	FAMILY	Genus species	common name	life form	SYMBOL
ANGIOSPERMS DICOTS	ASTERACEAE	*Pseudognaphalium obtusifolium*	rabbit-tobacco	forb/herb	pseobt
		Solidago fistulosa	pine barren goldenrod	forb/herb	solfis
		Solidago odora	anisescented goldenrod	forb/herb	solodo
		Solidago pulchra	Carolina goldenrod	forb/herb	solpul
		Solidago spp.	goldenrod	forb/herb	solsp.
		Solidago verna	springflowering goldenrod	forb/herb	solver
		Taraxacum spp.	dandelion	forb/herb	tarsp.
	CAMPANULACEAE	*Lobelia nuttallii*	Nuttall's lobelia	forb/herb	lobnut
	CLETHRACEAE	*Clethra alnifolia*	coastal sweetpepperbush	woody/woody	clealn
	CLUSIACEAE	*Hypericum crux-andreae*	St. Peterswort	woody/woody	hypsta
		Hypericum densiflorum	bushy St. Johnswort	woody/woody	hypden
		Hypericum hypericoides	St. Andrew's cross	woody/woody	hyphyp
		Hypericum reductum	Atlantic St. Johnswort	woody/woody	hypred
		Hypericum spp.	St. Johnswort	woody/woody	hypsp.
	CUSCUTACEAE	*Cuscuta spp.*	dodder	forb/herb	cussp.
	CYRILLACEAE	*Cyrilla racemiflora*	swamp titi	woody/woody	cyrrac
	DROSERACEAE	*Dionaea muscipula*	Venus flytrap	forb/herb	diomus
		Drosera spp.	sundew	forb/herb	drosp.

SECTION	FAMILY	*Genus species*	common name	life form	SYMBOL
ANGIOSPERMS DICOTS	DROSERACEAE	*Drosera brevifolia*	dwarf sundew	forb/herb	drobre
		Drosera capillaris	pink sundew	forb/herb	drocap
	EBENACEAE	*Diospyros virginiana*	common persimmon	woody/woody	diovir
	ERICACEAE	*Gaylussacia dumosa*	dwarf huckleberrry	woody/woody	gaydum
		Gaylussacia frondosa	blue huckleberry	woody/woody	gayfro
		Kalmia carolina	Carolina laurel	woody/woody	kalcar
		Lyonia ligustrina	maleberry	woody/woody	lyolig
		Lyonia lucida	fetterbush lyonia	woody/woody	lyoluc
		Lyonia mariana	piedmont staggerbush	woody/woody	lyomar
		Rhododendron atlanticum	dwarf azalea	woody/woody	rhoatl
		Vaccinium fuscatum	black highbush blueberry	woody/woody	vacfus
		Vaccinium corymbosum	highbush blueberry	woody/woody	vaccor
		Vaccinium crassifolium	creeping blueberry	woody/woody	vaccra
		Vaccinium tenellum	small black blueberry	woody/woody	vacten
		Zenobia pulverulenta	honeycup	woody/woody	zenpul
	FABACEAE	*Chamaecrista calycioides*	woodland sensitive pea	forb/herb	chacal
		Lespedeza cuneata	sericea lespedeza	forb/herb	lescun
	FAGACEAE	*Quercus spp.*	oak	woody/woody	quesp.
	GENTIANACEAE	*Bartonia virginica*	yellow screwstem	forb/herb	barvir
		Sabatia spp.	rose gentian	forb/herb	Sabsp.

<u>**SECTION**</u>	**FAMILY**	***Genus species***	**common name**	**life form**	**SYMBOL**
<u>ANGIOSPERMS DICOTS</u>	HAMAMELIDACEAE	*Liquidambar styraciflua*	sweetgum	woody/woody	liqsty
	LAURACEAE	*Persea borbonia*	redbay	woody/woody	perbor
	LENTIBULARIACEAE	*Utricularia juncea*	southern bladderwort	forb/herb	utrjun
	LOGANIACEAE	*Gelsemium sempervirens*	evening trumpetflower	vine/woody	gelsem
	MAGNOLIACEAE	*Magnolia virginiana*	sweetbay	woody/woody	magvir
	MELASTOMATACEAE	*Rhexia alifanus*	savannah meadowbeauty	forb/herb	rheali
		Rhexia lutea	yellow meadowbeauty	forb/herb	rhelut
		Rhexia mariana	Maryland meadowbeauty	forb/herb	rhemar
		Rhexia nashii	maid Marian	forb/herb	rhenas
		Rhexia petiolata	fringed meadowbeauty	forb/herb	rhepet
		Rhexia spp.	meadowbeauty	forb/herb	rhesp.
	MYRICACEA	*Morella cerifera*	waxmyrtle	woody/woody	morcer
		Morella caroliniensis	southern bayberry	woody/woody	morcar
	ONAGRACEAE	*Ludwigia alternifolia*	seedbox	forb/herb	ludalt
		Ludwigia maritima	seaside primrose-willow	forb/herb	ludmar
	POLYGALACEAE	*Polygala cruciata*	drumheads	forb/herb	polcru
		Polygala lutea	orange milkwort	forb/herb	pollut
		Polygala nana	candyroot	forb/herb	polnan

SECTION	FAMILY	*Genus species*	common name	life form	SYMBOL
ANGIOSPERMS DICOTS	ROSACEAE	*Photinia pyrifolia*	red chokeberry	woody/woody	phopyr
		Rubus spp.	blackberry	woody/woody	rubsp.
	RUBIACEAE	*Diodia teres*	poorjoe	forb/herb	dioter
		Mitchella repens	partridgeberry	forb/herb	mitrep
	SARRACENIACEAE	*Sarracenia flava*	yellow pitcherplant	forb/herb	sarfla
		Sarracenia purpurea	purple pitcherplant	forb/herb	sarpur
	SCROPHULARIACEAE	*Gratiola pilosa*	shaggy hedgehyssop	forb/herb	grapil
		Seymeria cassioides	yaupon blacksenna	forb/herb	seycas
	SYMPLOCACEAE	*Symplocos tinctoria*	common sweetleaf	woody/woody	symtin
	THEACEAE	*Gordonia lasianthus*	loblolly bay	woody/woody	gorlas
	VIOLACEAE	*Viola spp.*	violet	forb/herb	viosp.
	VITACEAE	*Vitis spp.*	grape	vine/woody	vitsp.
MONOCOTS					
	CYPERACEAE	*Carex striata var. brevis*	Walter's sedge	graminoid	CASTB
		Cyperus croceus	Baldwin's flatsedge	graminoid	CYCR6
		Cyperus spp.	flatsedge	small graminoid/herb	cypsp.
		Fimbristylis puberula	hairy fimbry	graminoid	FIPU
		Fuirena breviseta	saltmarsh umbrella-sedge	graminoid	FUBR
		Rhynchospora baldwinii	Baldwin's beaksedge	small graminoid/herb	rhybal

SECTION	FAMILY	Genus species	common name	life form	SYMBOL
MONOCOTS	CYPERACEAE	*Rhynchospora breviseta*	shortbristle beaksedge	small graminoid/herb	rhybre
		Rhynchospora chalarocephala	loosehead beaksedge	small graminoid/herb	rhycha
		Rhynchospora ciliaris	fringed beaksedge	small graminoid/herb	rhycil
		Rhynchospora debilis	savannah beaksedge	small graminoid/herb	rhydeb
		Rhynchospora fascicularis var. distans	fascicled beaksedge	small graminoid/herb	rhyfas v. dis
		Rhynchospora fascicularis var. fascicularis	fascicled beaksedge	small graminoid/herb	rhyfas v. fas
		Rhynchospora pallida	pale beaksedge	small graminoid/herb	rhypal
		Rhynchospora plumosa	plumed beaksedge	small graminoid/herb	rhyplu
		Rhynchospora spp.	beaksedge	small graminoid/herb	rhysp.
		Rhynchospora wrightiana	Wright's beaksedge	small graminoid/herb	rhywri
		Scleria ciliata var. glabra	fringed nutrush	small graminoid/herb	sclcil
		Scleria minor	slender nutrush	small graminoid/herb	sclmin
		Scleria muehlenbergii	Muehlenberg's nutrush	small graminoid/herb	sclmue

SECTION	FAMILY	Genus species	common name	life form	SYMBOL
MONOCOTS	ERIOCAULACEAE	*Eriocaulon compressum*	flattened pipewort	small graminoid/herb	ericom
		Eriocaulon spp.	pipewort	small graminoid/herb	erisp.
		Lachnocaulon anceps	whitehead bogbutton	small graminoid/herb	lacanc
		Lachnocaulon spp.	bogbutton	small graminoid/herb	lacsp.
	HAEMODORACEAE	*Lachnanthes carolina*	Carolina redroot	forb/herb	laccar
	IRIDACEAE	*Iris spp.*	iris	forb/herb	irisp.
		Iris verna	dwarf violet iris	forb/herb	iriver
	JUNCACEA	*Juncus spp.*	rush	graminoid	junsp.
	LILIACEAE	*Aletris farinosa*	white colicroot	forb/herb	alefar
		Amianthium muscitoxicum	flypoison	forb/herb	amimus
		Pleea tenuifolia	rush featherling	forb/herb	pleten
		Zigadenus densus	Osceola's plume	forb/herb	zigden
	ORCHIDACEAE	*Cleistes spp.*	rosebud orchid	forb/herb	clesp.
		Platanthera spp.	fringed orchid	forb/herb	plasp.
		Spiranthes spp.	lady's tresses	forb/herb	spisp.
	POACEAE	*Amphicarpum purshii*	blue maidencane	graminoid	amppur
		Andropogon capillipes	chalky bluestem	large graminoid/herb	andcap

SECTION	FAMILY	Genus species	common name	life form	SYMBOL
MONOCOTS	POACEAE	*Andropogon spp.*	bluestem	large graminoid/herb	andsp.
		Andropogon virginicus	broomsedge bluestem	large graminoid/herb	andvir
		Aristida stricta	pineland threeawn	large graminoid/herb	aristr
		Arundinaria gigantea	giant cane	large graminoid/herb	arugig
		Dichanthelium aciculare	needleleaf rosette grass	small graminoid/herb	dicaci
		Dichanthelium acuminatum var. fasciculatum	western panicgrass	large graminoid/herb	dicacu
		Dichanthelium dichotomum var. ensifolium	cypress panicgrass	graminoid	DIDIE
		Dichanthelium latifolium	broadleaf rosette grass	graminoid	DILA8
		Dichanthelium sabulorum	hemlock rosette grass	graminoid	DISA5
		Dichanthelium spp.	rosette grass	graminoid	DICHA2
		Dichanthelium strigosum var. leucoblepharis	roughhair rosette grass	graminoid	DISTL
		Eragrostis curvula	weeping lovegrass	large graminoid/herb	eracur
		Muhlenbergia expansa	cutover muhly	large graminoid/herb	muhexp
		Panicum rigidulum var. pubescens	redtop panicgrass	graminoid	PARIP

SECTION	FAMILY	Genus species	common name	life form	SYMBOL
MONOCOTS	POACEAE	*Panicum spp.*	panic grass	graminoid	PANIC
		Panicum verrucosum	warty panicgrass	graminoid	PAVE2
		Poa spp.	bluegrass	large graminoid/herb	poasp.
		Schizachyrium scoparium	little bluestem	large graminoid/herb	schsco
		Sporobulus pinetorum	Carolina dropseed	graminoid	SPPI3
	SMILACACEAE				
		Smilax bona-nox	saw greenbrier	vine/woody	smibon
		Smilax glauca	cat greenbrier	vine/woody	smigla
		Smilax laurifolia	laurel greenbrier	vine/woody	smilau
		Smilax rotundifolia	roundleaf greenbrier	vine/woody	smirot
		Smilax spp.	greenbrier	vine/woody	smisp.
	XYRIDACEAE				
		Xyris ambigua	coastal plain yelloweyed grass	forb/herb	xyramb
		Xyris baldwiniana	Baldwin's yelloweyed grass	forb/herb	xyrbal
		Xyris brevifolia	shortleaf yelloweyed grass	forb/herb	xyrbre
		Xyris caroliniana	carolina yelloweyed grass	forb/herb	xyrcar
		Xyris fimbriata	fringed yelloweyed grass	forb/herb	xyrfim
		Xyris spp.	yelloweyed grass	forb/herb	xyrsp.
		Xyris platylepis	tall yelloweyed grass	forb/herb	xyrpla

Appendix GL2. Species recorded in 2006 ranked by frequency of occurrence in all quadrats sampled (n = 480).

Species	Rank Number	Frequency	Relative Frequency	Proportion of Total	Cumulative Percent
dichsp.	1	315	65.63	0.06	6
vaccra	2	295	61.46	0.06	11
andcap	3	283	58.96	0.05	17
rhysp.	4	251	52.29	0.05	21
aroarb	5	223	46.46	0.04	26
ilegla	6	221	46.04	0.04	30
gayfro	7	218	45.42	0.04	34
ptraqu	8	192	40.00	0.04	38
schsch	9	173	36.04	0.03	41
aristr	10	171	35.63	0.03	44
pollut	11	164	34.17	0.03	47
xyrsp.	12	158	32.92	0.03	50
smilau	13	146	30.42	0.03	53
perbor	14	137	28.54	0.03	55
eupsp.	15	111	23.13	0.02	57
gaydum	16	98	20.42	0.02	59
rhepet	17	96	20.00	0.02	61
laccar	18	88	18.33	0.02	63
lyomar	19	77	16.04	0.01	64
vacten	20	73	15.21	0.01	66
lyoluc	21	72	15.00	0.01	67
irisp.	22	72	15.00	0.01	68
cypsp.	23	70	14.58	0.01	70
astsp.	24	70	14.58	0.01	71
rhenas	25	70	14.58	0.01	72
ilecor	26	69	14.38	0.01	74
pinpal	27	68	14.17	0.01	75
andvir	28	68	14.17	0.01	76
andsp.	29	67	13.96	0.01	77
woovir	30	59	12.29	0.01	78
euppil	31	59	12.29	0.01	80
smigla	32	59	12.29	0.01	81
rhyplu	33	53	11.04	0.01	82
cyrrac	34	50	10.42	0.01	83
osmcin	35	49	10.21	0.01	84
myrhet	36	45	9.38	0.01	84
solpul	37	44	9.17	0.01	85
myrcer	38	43	8.96	0.01	86
muhexp	39	42	8.75	0.01	87
cartom	40	42	8.75	0.01	88
rheali	41	37	7.71	0.01	88
lacanc	42	34	7.08	0.01	89
hypred	43	33	6.88	0.01	90
liagra	44	32	6.67	0.01	90
pleten	45	31	6.46	0.01	91

Species	Rank Number	Frequency	Relative Frequency	Proportion of Total	Cumulative Percent
carodo	46	31	6.46	0.01	91
poasp	47	31	6.46	0.01	92
gelsem	48	28	5.83	0.01	92
magvir	49	27	5.63	0.01	93
rhoatl	50	26	5.42	0.00	93
eupalb	51	24	5.00	0.00	94
pinsp.	52	22	4.58	0.00	94
pitgra	53	22	4.58	0.00	95
acerub	54	21	4.38	0.00	95
pansp.	55	21	4.38	0.00	95
solfis	56	21	4.38	0.00	96
vaccor	57	20	4.17	0.00	96
carsp.	58	14	2.92	0.00	96
clealn	59	13	2.71	0.00	97
amppur	60	13	2.71	0.00	97
arutec	61	11	2.29	0.00	97
eupcap	62	11	2.29	0.00	97
lyolig	63	9	1.88	0.00	98
ileopa	64	8	1.67	0.00	98
diomus	65	8	1.67	0.00	98
junsp.	66	8	1.67	0.00	98
lobnut	67	8	1.67	0.00	98
vacatt	68	7	1.46	0.00	98
zenpul	69	6	1.25	0.00	98
kalcar	70	6	1.25	0.00	99
pinell	71	6	1.25	0.00	99
gorlas	72	6	1.25	0.00	99
drocap	73	5	1.04	0.00	99
rubsp.	74	4	0.83	0.00	99
diovir	75	4	0.83	0.00	99
wooare	76	4	0.83	0.00	99
polcru	77	4	0.83	0.00	99
eutten	78	4	0.83	0.00	99
drobre	79	3	0.63	0.00	99
viosp.	80	3	0.63	0.00	99
bacham	81	2	0.42	0.00	99
erigsp	82	2	0.42	0.00	99
hypden	83	2	0.42	0.00	99
hypsta	84	2	0.42	0.00	99
drosp.	85	2	0.42	0.00	100
ludalt	86	2	0.42	0.00	100
plasp.	87	2	0.42	0.00	100
sarfla	88	2	0.42	0.00	100
solodo	89	2	0.42	0.00	100
zigden	90	2	0.42	0.00	100
spopin	91	1	0.21	0.00	100
polnan	92	1	0.21	0.00	100
rhucop	93	1	0.21	0.00	100

Species	Rank Number	Frequency	Relative Frequency	Proportion of Total	Cumulative Percent
ambart	94	1	0.21	0.00	100
rhycil	95	1	0.21	0.00	100
cascal	96	1	0.21	0.00	100
ilemyr	97	1	0.21	0.00	100
amimus	98	1	0.21	0.00	100
astlin	99	1	0.21	0.00	100
clesp.	100	1	0.21	0.00	100
cussp.	101	1	0.21	0.00	100
gnaobt	102	1	0.21	0.00	100
rhemar	103	1	0.21	0.00	100
sabsp.	104	1	0.21	0.00	100
sarpur	105	1	0.21	0.00	100
smisp.	106	1	0.21	0.00	100

Appendix GL3. Means and standard errors of total vegetation A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

A) Cover

Means	Year		
Treatment	2004	2005	2006
CB	49.28	92.73	82.77
CF	59.13	108.86	79.18
CHB	19.88	74.98	81.48
CM	35.18	76.24	77.85
HB	25.73	63.53	67.56
HF	32.37	62.04	70.23
HM	28.28	63.10	66.34
F	73.07	96.93	84.07
Herbicide	26.57	65.91	71.40
No herbicide	54.16	93.69	80.96
Flat*	45.75	85.45	74.71
Mechanical	34.62	73.90	73.56

Standard errors	Year		
Treatment	2004	2005	2006
CB	3.67	4.67	3.73
CF	3.14	4.10	2.76
CHB	2.20	3.93	3.61
CM	3.12	4.16	2.88
HB	2.53	3.48	3.22
HF	3.39	4.23	4.11
HM	4.92	4.04	2.88
F	4.79	3.66	3.07
Herbicide	5.07	4.46	4.31
No herbicide	4.38	3.04	2.86
Flat*	4.47	5.32	4.43
Mechanical	4.69	3.97	3.51

B) Richness

Means	Year		
Treatment	2004	2005	2006
CB	9.77	11.13	12.63
CF	11.77	12.52	12.85
CHB	5.48	10.47	11.30
CM	9.08	10.77	11.72
HB	6.10	9.43	9.58
HF	6.33	8.28	10.13
HM	6.02	9.25	10.75
F	9.80	10.18	11.60
Herbicide	5.98	9.36	10.44
No herbicide	10.10	11.15	12.20
Flat*	9.05	10.40	11.49
Mechanical	7.74	10.15	11.17

Standard errors	Year		
Treatment	2004	2005	2006
CB	0.43	0.43	1.30
CF	0.41	0.38	0.37
CHB	0.45	0.35	0.37
CM	0.51	0.52	0.49
HB	0.48	0.41	0.42
HF	0.44	0.48	0.60
HM	0.44	0.50	0.39
F	0.49	0.45	0.44
Herbicide	0.64	0.73	0.67
No herbicide	0.39	0.50	0.61
Flat*	0.45	0.75	0.73
Mechanical	0.66	0.58	0.47

*Analysis of flat vs. mechanical excluded the treatments F and BCH to balance the effects of herbicide and chopping in the analysis.

Appendix GL4. Means and standard errors of herbaceous A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

A) Cover

Means		Year	
Treatment	2004	2005	2006
CB	21.26	34.98	29.70
CF	28.28	45.41	40.73
CHB	13.48	44.65	52.78
CM	15.51	34.25	33.81
HB	15.75	37.99	44.17
HF	14.64	28.71	36.00
HM	18.58	41.59	44.17
F	23.89	29.42	31.40
Herbicide	15.61	38.24	44.28
No herbicide	22.24	36.01	33.91
Flat	21.46	37.06	38.36
Mechanical	17.78	37.20	37.96

Standard errors		Year	
Treatment	2004	2005	2006
CB	4.19	4.53	1.32
CF	3.02	1.60	2.94
CHB	2.91	3.85	3.79
CM	2.31	1.83	4.31
HB	3.80	5.30	5.23
HF	4.35	6.62	6.71
HM	4.31	2.02	2.71
F	6.66	8.43	8.90
Herbicide	2.87	2.58	3.27
No herbicide	2.55	3.11	2.86
Flat	2.69	3.93	4.51
Mechanical	2.35	2.46	2.37

B) Richness

Means		Year	
Treatment	2004	2005	2006
CB	4.27	5.70	5.78
CF	6.15	6.75	7.22
CHB	3.33	6.38	7.52
CM	4.35	5.67	6.58
HB	3.82	5.90	6.47
HF	3.83	5.12	6.58
HM	3.97	5.98	7.28
F	4.95	4.82	6.02
Herbicide	3.74	5.85	6.96
No herbicide	4.93	5.73	6.40
Flat	4.99	5.93	6.90
Mechanical	4.10	5.81	6.26

Standard errors		Year	
Treatment	2004	2005	2006
CB	0.49	0.51	0.57
CF	0.64	0.53	0.56
CHB	0.59	0.40	0.74
CM	0.55	0.43	0.60
HB	0.81	0.76	0.66
HF	0.79	1.11	1.20
HM	0.45	0.59	0.68
F	1.30	1.02	1.46
Herbicide	0.56	0.66	0.78
No herbicide	0.44	0.55	0.62
Flat	0.62	0.81	0.84
Mechanical	0.50	0.52	0.53

*Analysis of flat vs. mechanical excluded the treatments F and BCH to balance the effects of herbicide and chopping in the analysis.

Appendix GL5. Means and standard errors of total woody A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

A) Cover

Means		Year	
Treatment	2004	2005	2006
CB	28.02	57.75	53.04
CF	30.85	63.45	38.39
CHB	6.40	30.33	28.54
CM	19.68	41.99	43.99
HB	9.98	25.54	23.36
HF	17.73	33.33	34.18
HM	9.70	21.51	22.13
F	49.18	67.51	52.52
Herbicide	10.95	27.68	27.05
No herbicide	31.93	57.68	46.99
Flat*	24.29	48.39	36.29
Mechanical	16.84	36.70	35.63

Standard errors		Year	
Treatment	2004	2005	2006
CB	5.51	8.95	5.12
CF	3.43	5.35	5.65
CHB	1.48	4.93	4.84
CM	2.95	3.41	5.09
HB	2.86	5.02	4.80
HF	5.58	6.46	8.53
HM	2.96	3.13	2.10
F	12.16	8.27	10.52
Herbicide	2.85	4.03	4.69
No herbicide	5.09	5.60	4.77
Flat*	3.99	5.09	6.45
Mechanical	2.53	3.59	2.39

B) Richness

Means		Year	
Treatment	2004	2005	2006
CB	5.50	5.43	5.60
CF	5.68	5.77	5.63
CHB	2.15	4.08	3.78
CM	4.77	5.10	5.13
HB	2.28	3.53	3.12
HF	2.50	3.17	3.55
HM	2.05	3.27	3.47
F	4.87	5.37	5.58
Herbicide	2.25	3.51	3.48
No herbicide	5.20	5.42	5.49
Flat*	4.09	4.47	4.59
Mechanical	3.65	4.33	4.33

Standard errors		Year	
Treatment	2004	2005	2006
CB	0.39	0.12	0.33
CF	0.13	0.24	0.38
CHB	0.24	0.33	0.36
CM	0.28	0.34	0.18
HB	0.38	0.51	0.43
HF	0.36	0.16	0.21
HM	0.44	0.49	0.35
F	0.29	0.47	0.43
Herbicide	0.27	0.30	0.26
No herbicide	0.17	0.18	0.26
Flat*	0.21	0.19	0.24
Mechanical	0.24	0.17	0.21

*Analysis of flat vs. mechanical excluded the treatments F and BCH to balance the effects of herbicide and chopping in the analysis.

Appendix GL6. Means and standard errors of large graminoid A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

A) Cover

Means		Year	
Treatment	2004	2005	2006
CB	8.29	13.85	12.63
CF	11.52	19.37	16.24
CHB	0.80	7.41	16.93
CM	5.55	12.47	11.64
HB	3.04	10.22	14.38
HF	2.62	9.13	16.48
HM	1.63	8.38	14.19
F	10.13	16.19	11.76
Herbicide	2.02	8.78	15.49
No herbicide	8.87	15.47	13.07
Flat*	7.07	14.25	16.36
Mechanical	4.63	11.23	13.21

Standard errors		Year	
Treatment	2004	2005	2006
CB	1.82	2.89	1.09
CF	2.67	2.44	1.88
CHB	0.30	1.62	1.68
CM	1.31	2.17	1.10
HB	0.69	3.02	1.90
HF	0.86	1.05	4.51
HM	0.47	2.19	2.03
F	3.51	5.83	3.95
Herbicide	0.41	1.67	2.30
No herbicide	1.54	2.49	1.75
Flat*	1.66	1.33	3.06
Mechanical	0.36	2.03	1.20

B) Richness

Means		Year	
Treatment	2004	2005	2006
CB	1.00	1.27	1.57
CF	1.48	1.82	2.10
CHB	0.23	0.87	1.73
CM	0.95	1.08	1.43
HB	0.78	1.08	1.67
HF	0.70	1.18	1.80
HM	0.57	0.92	1.80
F	1.15	1.33	1.72
Herbicide	0.57	1.01	1.75
No herbicide	1.15	1.38	1.70
Flat*	1.09	1.50	1.95
Mechanical	0.83	1.09	1.62

Standard errors		Year	
Treatment	2004	2005	2006
CB	0.21	0.12	0.10
CF	0.22	0.14	0.30
CHB	0.08	0.17	0.20
CM	0.12	0.24	0.10
HB	0.16	0.14	0.10
HF	0.22	0.18	0.24
HM	0.13	0.11	0.18
F	0.28	0.33	0.49
Herbicide	0.11	0.13	0.14
No herbicide	0.07	0.16	0.20
Flat*	0.19	0.15	0.23
Mechanical	0.04	0.13	0.10

*Analysis of flat vs. mechanical excluded the treatments F and BCH to balance the effects of herbicide and chopping in the analysis.

Appendix GL7. Means and standard errors of small graminoid A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

A) Cover

Means		Year		Standard errors		Year	
Treatment	2004	2005	2006	Treatment	2004	2005	2006
CB	4.52	7.73	6.41	CB	2.38	1.19	1.05
CF	5.56	10.58	7.03	CF	0.84	1.46	1.36
CHB	4.05	17.10	11.90	CHB	1.49	3.21	3.63
CM	3.40	9.19	9.24	CM	0.55	1.26	1.95
HB	4.90	11.37	11.82	HB	1.97	1.18	1.56
HF	6.52	9.35	7.70	HF	3.88	2.01	2.05
HM	7.42	13.33	9.70	HM	1.82	0.93	2.64
F	5.38	4.45	6.25	F	1.57	1.11	2.07
Herbicide	5.72	12.79	10.28	Herbicide	2.14	1.05	1.97
No herbicide	4.71	7.99	7.23	No herbicide	0.87	0.45	1.11
Flat*	6.04	9.96	7.37	Flat*	1.88	1.33	1.67
Mechanical	5.06	10.40	9.29	Mechanical	1.56	0.54	1.44

B) Richness

Means		Year		Standard errors		Year	
Treatment	2004	2005	2006	Treatment	2004	2005	2006
CB	1.05	1.72	1.35	CB	0.20	0.16	0.11
CF	1.18	1.73	1.60	CF	0.07	0.15	0.12
CHB	1.10	2.45	1.58	CHB	0.26	0.16	0.16
CM	1.10	1.80	1.90	CM	0.19	0.20	0.22
HB	1.12	2.23	1.53	HB	0.18	0.23	0.04
HF	1.23	1.83	1.72	HF	0.24	0.32	0.53
HM	1.17	2.17	1.50	HM	0.15	0.22	0.15
F	1.13	1.25	1.32	F	0.33	0.24	0.27
Herbicide	1.15	2.17	1.58	Herbicide	0.17	0.21	0.14
No herbicide	1.12	1.63	1.54	No herbicide	0.11	0.15	0.12
Flat*	1.21	1.78	1.66	Flat*	0.13	0.23	0.16
Mechanical	1.11	1.98	1.57	Mechanical	0.15	0.16	0.09

*Analysis of flat vs. mechanical excluded the treatments F and BCH to balance the effects of herbicide and chopping in the analysis.

Appendix GL8. Means and standard errors of forb A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

A) Cover

Means	Year		
Treatment	2004	2005	2006
CB	5.76	11.08	7.30
CF	7.53	10.25	10.47
CHB	2.25	11.39	11.95
CM	4.65	9.48	9.08
HB	2.77	10.11	9.61
HF	2.83	7.42	7.85
HM	4.37	10.40	11.22
F	6.08	6.92	9.28
Herbicide	3.05	9.83	10.16
No herbicide	6.01	9.43	9.03
Flat*	5.18	8.83	9.16
Mechanical	4.39	10.26	9.30

Standard errors	Year		
Treatment	2004	2005	2006
CB	2.21	3.06	0.85
CF	1.32	1.12	1.89
CHB	0.61	2.44	3.15
CM	0.66	1.20	1.39
HB	1.17	3.55	2.97
HF	0.85	3.33	2.48
HM	1.20	3.00	2.46
F	0.85	2.44	2.90
Herbicide	0.73	2.93	2.63
No herbicide	1.04	1.22	1.01
Flat*	0.89	1.96	1.95
Mechanical	0.93	2.08	1.41

B) Richness

Means	Year		
Treatment	2004	2005	2006
CB	1.47	2.48	2.45
CF	2.08	2.65	2.87
CHB	0.90	2.50	3.28
CM	1.60	2.32	2.67
HB	0.93	2.05	2.60
HF	1.13	1.67	2.58
HM	1.08	2.30	3.15
F	1.85	1.90	2.47
Herbicide	1.01	2.13	2.90
No herbicide	1.75	2.34	2.61
Flat*	1.61	2.16	2.73
Mechanical	1.27	2.29	2.72

Standard errors	Year		
Treatment	2004	2005	2006
CB	0.41	0.40	0.43
CF	0.37	0.31	0.45
CHB	0.24	0.37	0.68
CM	0.29	0.19	0.49
HB	0.33	0.53	0.63
HF	0.34	0.61	0.82
HM	0.34	0.49	0.74
F	0.59	0.55	0.67
Herbicide	0.28	0.48	0.69
No herbicide	0.24	0.30	0.38
Flat*	0.32	0.45	0.62
Mechanical	0.27	0.34	0.45

*Analysis of flat vs. mechanical excluded the treatments F and BCH to balance the effects of herbicide and chopping in the analysis.

Appendix GL9. Means and standard errors of fern A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

A) Cover

Means	Year		
Treatment	2004	2005	2006
CB	2.69	4.29	3.37
CF	3.68	5.34	6.98
CHB	6.38	10.58	12.01
CM	1.91	5.37	3.84
HB	5.04	7.42	8.37
HF	2.68	2.90	3.97
HM	5.17	9.39	9.06
F	2.30	2.80	4.11
Herbicide	4.82	7.57	8.35
No herbicide	2.64	4.45	4.58
Flat*	3.18	4.12	5.48
Mechanical	3.70	6.62	6.16

Standard errors	Year		
Treatment	2004	2005	2006
CB	0.70	1.36	1.09
CF	0.91	1.54	1.59
CHB	1.53	3.03	3.36
CM	0.59	1.62	1.79
HB	1.26	1.77	2.40
HF	1.75	1.31	1.52
HM	3.17	3.13	2.61
F	1.20	2.02	1.84
Herbicide	1.29	1.63	1.73
No herbicide	0.60	1.23	0.88
Flat*	1.18	1.10	1.24
Mechanical	1.04	1.22	1.53

B) Richness

Means	Year		
Treatment	2004	2005	2006
CB	0.38	0.42	0.42
CF	0.63	0.60	0.65
CHB	0.72	0.72	0.92
CM	0.42	0.63	0.58
HB	0.57	0.63	0.67
HF	0.40	0.47	0.48
HM	0.57	0.65	0.83
F	0.40	0.45	0.52
Herbicide	0.56	0.62	0.73
No herbicide	0.46	0.53	0.54
Flat*	0.52	0.53	0.57
Mechanical	0.48	0.58	0.63

Standard errors	Year		
Treatment	2004	2005	2006
CB	0.09	0.11	0.15
CF	0.09	0.12	0.15
CHB	0.11	0.09	0.13
CM	0.10	0.16	0.16
HB	0.10	0.11	0.12
HF	0.15	0.18	0.11
HM	0.11	0.08	0.13
F	0.17	0.15	0.12
Herbicide	0.08	0.08	0.09
No herbicide	0.08	0.12	0.10
Flat*	0.10	0.13	0.11
Mechanical	0.05	0.09	0.12

*Analysis of flat vs. mechanical excluded the treatments F and BCH to balance the effects of herbicide and chopping in the analysis.

Appendix GL10. Means and standard errors of woody group A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

A) Cover

Means		Year	
Treatment	2004	2005	2006
CB	22.57	44.96	43.90
CF	24.64	48.53	30.65
CHB	4.64	20.88	20.33
CM	15.95	33.12	37.24
HB	7.65	17.33	17.40
HF	15.67	26.39	27.11
HM	6.54	15.50	15.99
F	39.23	53.34	42.48
Herbicide	8.63	20.03	20.21
No herbicide	25.60	44.99	38.57
Flat*	20.15	37.46	28.88
Mechanical	13.18	27.73	28.63

Standard errors		Year	
Treatment	2004	2005	2006
CB	4.06	6.50	4.19
CF	2.59	4.84	4.73
CHB	1.18	3.64	5.03
CM	2.34	2.41	3.53
HB	2.19	4.12	4.66
HF	5.51	7.45	8.78
HM	1.85	2.41	2.60
F	12.21	9.72	10.59
Herbicide	2.50	3.58	5.04
No herbicide	4.49	4.78	4.20
Flat*	3.77	5.44	6.18
Mechanical	2.01	2.52	2.18

B) Richness

Means		Year	
Treatment	2004	2005	2006
CB	4.40	4.13	4.32
CF	4.50	4.48	4.33
CHB	1.53	2.75	2.55
CM	3.88	3.88	4.18
HB	1.78	2.43	2.18
HF	1.85	2.40	2.70
HM	1.45	2.12	2.40
F	3.78	4.12	4.38
Herbicide	1.65	2.43	2.46
No herbicide	4.14	4.15	4.30
Flat*	3.18	3.44	3.52
Mechanical	2.88	3.14	3.27

Standard errors		Year	
Treatment	2004	2005	2006
CB	0.24	0.09	0.24
CF	0.13	0.25	0.39
CHB	0.21	0.36	0.30
CM	0.29	0.25	0.14
HB	0.32	0.53	0.46
HF	0.40	0.15	0.19
HM	0.39	0.35	0.36
F	0.26	0.44	0.42
Herbicide	0.28	0.28	0.29
No herbicide	0.11	0.17	0.23
Flat*	0.22	0.18	0.24
Mechanical	0.17	0.17	0.21

*Analysis of flat vs. mechanical excluded the treatments F and BCH to balance the effects of herbicide and chopping in the analysis.

Appendix GL11. Means and standard errors of vine A) cover and B) richness by study treatment, chemical treatment, and mechanical treatment in 2004, 2005, and 2006

A) Cover

Means		Year	
Treatment	2004	2005	2006
CB	5.45	10.82	9.14
CF	6.21	14.79	7.74
CHB	1.76	7.61	8.21
CM	3.73	6.63	6.75
HB	2.33	7.09	5.96
HF	2.06	6.86	7.08
HM	3.16	6.10	6.13
F	9.95	13.23	10.04
Herbicide	2.33	6.91	6.84
No herbicide	6.33	11.36	8.42
Flat*	4.13	10.83	7.41
Mechanical	3.67	7.66	7.00

Standard errors		Year	
Treatment	2004	2005	2006
CB	1.67	3.17	1.62
CF	1.32	2.11	1.53
CHB	0.36	1.11	0.62
CM	0.81	1.32	1.65
HB	0.82	0.84	1.21
HF	0.65	2.06	3.99
HM	1.21	0.77	1.20
F	3.52	3.42	1.81
Herbicide	0.42	0.63	1.38
No herbicide	1.03	1.23	1.06
Flat*	0.94	2.08	2.44
Mechanical	0.62	1.13	0.81

B) Richness

Means		Year	
Treatment	2004	2005	2006
CB	1.10	1.12	1.28
CF	1.83	1.23	1.30
CHB	0.62	1.18	1.23
CM	0.88	1.05	0.95
HB	0.50	1.00	0.93
HF	0.65	0.73	0.85
HM	0.60	1.10	1.07
F	1.08	1.13	1.20
Herbicide	0.59	1.00	1.02
No herbicide	1.06	1.13	1.18
Flat*	0.92	0.98	1.08
Mechanical	0.77	1.07	1.06

Standard errors		Year	
Treatment	2004	2005	2006
CB	0.20	0.14	0.16
CF	0.14	0.19	0.18
CHB	0.09	0.07	0.10
CM	0.06	0.10	0.14
HB	0.10	0.05	0.06
HF	0.12	0.08	0.13
HM	0.11	0.10	0.08
F	0.15	0.13	0.13
Herbicide	0.05	0.05	0.05
No herbicide	0.01	0.08	0.10
Flat*	0.13	0.12	0.09
Mechanical	0.08	0.06	0.08

*Analysis of flat vs. mechanical excluded the treatments F and BCH to balance the effects of herbicide and chopping in the analysis.

Appendix GL12. Means and standard errors of total vegetation richness at each scale in A) 2004, B) 2005, C) 2006, and D) all years.

A) 2004

Means	Scale (m^2)			
Treatment	0.1	1	10	100
CB	3.20	12.00	22.60	28.60
CF	5.00	11.00	18.80	29.20
CHB	3.60	9.40	17.00	23.00
CM	3.00	7.20	15.80	26.40
HB	1.80	7.20	15.20	23.00
HF	2.20	8.40	15.60	23.60
HM	1.40	5.20	14.40	23.40
F	4.60	9.20	18.60	27.00

Standard errors	Scale (m^2)			
Treatment	0.1	1	10	100
CB	0.73	1.73	2.60	2.29
CF	1.00	1.52	2.27	2.06
CHB	0.87	1.96	2.86	2.51
CM	1.10	0.97	2.96	1.44
HB	0.66	1.98	2.92	3.16
HF	0.80	1.44	2.16	2.50
HM	0.51	1.24	1.66	2.48
F	0.75	2.03	2.98	2.70

B) 2005

Means	Scale (m^2)			
Treatment	0.1	1	10	100
CB	3.80	11.00	19.80	28.20
CF	6.00	11.00	17.00	26.20
CHB	6.20	13.80	21.80	28.60
CM	4.60	10.80	19.60	32.00
HB	3.00	9.20	19.20	25.80
HF	4.20	8.20	18.80	26.20
HM	3.20	8.40	14.80	21.80
F	4.60	9.00	16.40	26.60

Standard errors	Scale (m^2)			
Treatment	0.1	1	10	100
CB	0.58	0.71	2.50	2.03
CF	0.71	1.00	1.58	2.18
CHB	1.83	1.85	1.85	1.21
CM	1.25	1.83	4.25	1.76
HB	0.55	1.74	2.58	3.46
HF	1.07	1.16	2.67	2.37
HM	1.07	1.03	1.50	1.91
F	1.08	2.85	2.56	2.87

Appendix GL12 (cont). Means and standard errors of total vegetation richness at each scale in A) 2004, B) 2005, C) 2006 and D) all years

C) 2006

Means	Scale (m^2)			
Treatment	0.1	1	10	100
CB	5.40	12.60	22.20	33.80
CF	6.40	12.40	21.20	31.80
CHB	4.20	12.80	22.60	31.80
CM	4.80	10.00	19.60	27.40
HB	4.80	11.40	20.40	30.00
HF	4.80	14.80	20.20	27.20
HM	4.40	10.80	16.80	24.80
F	5.20	11.20	20.00	27.60

Standard errors	Scale (m^2)			
Treatment	0.1	1	10	100
CB	1.40	2.62	1.91	2.62
CF	1.08	1.29	2.06	2.87
CHB	0.49	1.16	1.17	1.46
CM	0.58	1.41	2.54	2.94
HB	1.46	2.62	3.08	2.68
HF	0.73	1.02	1.53	2.08
HM	0.68	1.11	2.24	2.60
F	0.66	1.50	3.21	3.23

D) All years

Means	Scale (m^2)			
Treatment	0.1	1	10	100
CB	4.13	11.87	21.53	30.20
CF	5.80	11.47	19.00	29.07
CHB	4.67	12.00	20.47	27.80
CM	4.13	9.33	18.33	28.60
HB	3.20	9.27	18.27	26.27
HF	3.73	10.47	18.20	25.67
HM	3.00	8.13	15.27	23.33
F	4.80	9.80	18.33	27.07
Herbicide	3.65	9.97	18.05	25.77
No herbicide	4.72	10.62	19.30	28.73
Flat*	4.77	10.97	18.60	27.37
Mechanical	3.62	9.65	18.35	27.10

Standard errors	Scale (m^2)			
Treatment	0.1	1	10	100
CB	0.58	1.01	1.30	1.42
CF	0.53	0.71	1.16	1.42
CHB	0.71	1.04	1.29	1.37
CM	0.58	0.88	1.84	1.32
HB	0.62	1.24	1.64	1.83
HF	0.56	1.05	1.27	1.31
HM	0.53	0.86	1.02	1.30
F	0.46	1.20	1.61	1.58
Herbicide	0.31	0.55	0.69	0.75
No herbicide	0.28	0.49	0.75	0.72
Flat*	0.42	0.63	0.85	1.00
Mechanical	0.29	0.52	0.78	0.80

*Analysis of flat vs. mechanical excluded the treatments F and BCH to balance the effects of herbicide and chopping in the analysis.

Appendix GL13. Means and standard errors of forb richness across all years at each scale

Forbs

Means	Scale (m^2)			
Treatment	0.1	1	10	100
CB	0.53	2.53	5.67	8.87
CF	0.53	2.40	4.73	8.27
CHB	1.20	2.93	5.93	9.00
CM	0.93	1.93	4.53	8.00
HB	0.93	2.27	5.47	7.60
HF	0.53	2.53	4.87	7.20
HM	0.73	2.00	4.07	6.27
F	0.87	2.73	5.27	8.53
Herbicide	0.85	2.43	5.08	7.52
No herbicide	0.72	2.40	5.05	8.42
Flat*	0.53	2.47	4.80	7.73
Mechanical	0.78	2.18	4.93	7.68

Standard errors	Scale (m^2)			
Treatment	0.1	1	10	100
CB	0.19	0.55	0.84	0.82
CF	0.19	0.45	0.75	0.84
CHB	0.20	0.46	0.67	0.68
CM	0.23	0.37	0.77	0.91
HB	0.36	0.59	0.78	0.89
HF	0.24	0.67	0.72	0.99
HM	0.27	0.45	0.68	0.75
F	0.34	0.90	1.05	1.20
Herbicide	0.14	0.27	0.36	0.43
No herbicide	0.12	0.30	0.42	0.47
Flat*	0.15	0.39	0.51	0.64
Mechanical	0.13	0.24	0.39	0.43

*Analysis of flat vs. mechanical excluded the treatments F and BCH to balance the effects of herbicide and chopping in the analysis.

Appendix GL14. Means and standard errors of shrub richness across all years at each scale

Woody

Means	Scale (m^2)			
Treatment	0.1	1	10	100
CB	1.80	4.80	8.67	11.47
CF	2.53	4.40	7.20	11.47
CHB	0.93	3.27	6.47	9.00
CM	1.60	3.40	6.00	10.40
HB	0.40	1.87	4.73	8.40
HF	1.20	2.40	5.07	7.53
HM	0.40	1.93	3.87	7.00
F	1.87	3.07	7.80	11.47
Herbicide	0.73	2.37	5.03	7.98
No herbicide	1.95	3.92	7.42	11.20
Flat*	1.87	3.40	6.13	9.50
Mechanical	1.05	3.00	5.82	9.32

Standard errors	Scale (m^2)			
Treatment	0.1	1	10	100
CB	0.40	0.55	0.71	0.64
CF	0.38	0.40	0.45	0.60
CHB	0.24	0.58	0.62	0.70
CM	0.34	0.45	0.76	0.54
HB	0.13	0.41	0.64	0.84
HF	0.34	0.36	0.60	0.51
HM	0.13	0.27	0.34	0.48
F	0.34	0.46	0.85	0.88
Herbicide	0.13	0.22	0.30	0.33
No herbicide	0.18	0.25	0.37	0.34
Flat*	0.28	0.32	0.42	0.53
Mechanical	0.16	0.26	0.39	0.38

*Analysis of flat vs. mechanical excluded the treatments F and BCH to balance the effects of herbicide and chopping in the analysis.

Appendix GL15. Frequency of occurrence for each species encountered in each experimental treatment in (A) 2004, (B) 2005, and (C) 2006. Frequency is percentage of 12 square meter vegetation sample quadrats per treatment unit in which the species was found. Figures are the treatment mean and standard error over 6 experimental blocks. Treatments are described in the text; "ALL" is mean across all treatments; species codes are defined in Appendix GL1. * indicates significant (P<.05) treatment effect; + indicates significant (P<.05) herbicide effect. Treatment effects determined ay analyses of variance.

A. 2004																			
TREATMENT		**ALL**		**CB**		**CF**		**CHB**		**CM**		**F**		**HB**		**HF**		**HM**	
Rank	Species	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
1	dichsp	52.29	3.64	58.33	6.97	68.33	10.34	56.67	13.02	41.67	6.97	43.33	12.19	51.67	8.08	41.67	16.03	56.67	5.53
2	vaccra*+	50.83	3.71	65.00	8.50	76.67	8.90	26.67	4.86	55.00	5.65	68.33	4.86	31.67	6.67	40.00	11.61	43.33	9.28
3	rhysp	45.42	4.50	30.00	7.73	41.67	9.13	43.33	12.19	48.33	14.77	53.33	14.09	38.33	12.80	63.33	11.96	45.00	19.83
4	ilegla*+	38.33	4.08	58.33	11.49	61.67	8.98	20.00	5.00	46.67	15.94	46.67	10.74	28.33	7.73	28.33	6.77	16.67	7.91
5	gayfro*+	37.29	4.13	51.67	8.08	61.67	9.72	36.67	12.53	45.00	7.26	61.67	9.72	20.00	7.26	11.67	4.25	10.00	3.12
6	aristr*+	35.63	3.86	41.67	6.97	61.67	8.16	6.67	4.08	43.33	10.34	53.33	11.67	25.00	7.91	26.67	9.28	26.67	9.28
7	ptraqu+	35.21	3.79	18.33	6.12	41.67	8.33	46.67	15.05	28.33	10.07	21.67	6.77	41.67	10.54	35.00	15.46	48.33	8.08
8	aroarb*+	35.21	4.52	70.00	8.98	53.33	10.74	18.33	6.67	60.00	10.99	48.33	7.17	8.33	3.73	10.00	3.12	13.33	6.77
9	perbor*+	25.42	2.81	35.00	3.12	41.67	9.86	13.33	4.25	23.33	6.67	43.33	1.67	16.67	5.89	25.00	8.33	5.00	3.33
10	pollut	22.71	2.83	20.00	4.25	35.00	7.17	8.33	3.73	13.33	5.65	40.00	13.79	18.33	5.53	25.00	9.13	21.67	3.33
11	smilau	22.50	2.90	26.67	5.53	16.67	9.50	30.00	12.25	25.00	4.56	26.67	7.64	18.33	12.19	21.67	7.26	15.00	7.17
12	pinpal*	21.25	2.13	20.00	3.33	13.33	3.33	23.33	3.12	36.67	3.33	6.67	3.12	26.67	5.53	10.00	4.86	33.33	6.46
13	schsch+	19.17	2.93	25.00	6.97	33.33	9.50	3.33	2.04	25.00	9.50	21.67	10.07	18.33	8.08	16.67	8.74	10.00	6.12
14	andcap	18.54	2.79	11.67	5.65	35.00	10.67	8.33	2.64	16.67	9.50	26.67	10.34	21.67	8.58	16.67	4.56	11.67	5.00
15	poasp	14.58	2.73	16.67	6.97	6.67	4.08	8.33	5.27	20.00	10.74	10.00	4.86	21.67	11.96	18.33	9.28	15.00	8.08
16	ilecor+	14.37	2.46	18.33	6.12	23.33	7.17	3.33	2.04	18.33	9.65	15.00	9.28	20.00	8.98	8.33	3.73	8.33	4.56
17	gaydum*+	14.17	2.50	18.33	8.50	25.00	2.64	0.00	0.00	26.67	10.67	30.00	4.25	3.33	2.04	3.33	2.04	6.67	3.12
18	vacten*+	13.96	3.12	25.00	11.79	46.67	7.73	1.67	1.67	23.33	7.17	8.33	2.64	1.67	1.67	0.00	0.00	5.00	5.00
19	lyomar*+	13.13	2.91	26.67	6.67	33.33	10.87	1.67	1.67	23.33	12.47	13.33	5.65	1.67	1.67	1.67	1.67	3.33	2.04
20	lyoluc*+	12.92	2.95	21.67	6.24	8.33	2.64	1.67	1.67	18.33	8.08	33.33	12.64	1.67	1.67	16.67	12.91	1.67	1.67
21	eupsp	11.67	2.17	8.33	6.45	8.33	4.56	18.33	6.67	8.33	4.56	10.00	4.08	16.67	10.87	10.00	6.67	13.33	5.65
22	myrcer	10.21	1.75	15.00	1.67	23.33	9.65	3.33	2.04	6.67	1.67	8.33	2.64	5.00	3.33	3.33	2.04	16.67	4.56
23	laccar	9.58	2.52	21.67	13.33	3.33	2.04	16.67	9.50	16.67	7.91	6.67	3.12	8.33	6.45	1.67	1.67	1.67	1.67
24	irisp	8.75	1.98	15.00	7.17	21.67	7.73	3.33	2.04	20.00	5.65	0.00	0.00	0.00	0.00	1.67	1.67	8.33	3.73

25	xyrsp	8.75	1.91	1.67	1.67	15.00	8.08	6.67	3.12	13.33	6.77	15.00	7.17	5.00	3.33	10.00	6.67	3.33	2.04
26	osmcin	8.12	1.90	6.67	4.08	15.00	7.17	11.67	6.24	5.00	3.33	6.67	4.86	11.67	9.72	1.67	1.67	6.67	3.12
27	carodo	7.92	1.86	6.67	3.12	18.33	8.50	3.33	3.33	5.00	3.33	15.00	9.28	8.33	3.73	5.00	2.04	1.67	1.67
28	woovir	7.71	2.18	13.33	7.73	6.67	6.67	13.33	11.37	8.33	3.73	11.67	8.17	3.33	2.04	3.33	3.33	1.67	1.67
29	cyrrac	7.71	2.41	1.67	1.67	0.00	0.00	5.00	3.33	5.00	3.33	6.67	4.08	3.33	2.04	30.00	15.05	10.00	4.86
30	rhenas	6.87	1.40	5.00	3.33	8.33	4.56	6.67	4.86	3.33	2.04	6.67	4.08	6.67	4.86	6.67	3.12	11.67	5.65
31	carsp	6.04	1.81	1.67	1.67	11.67	7.73	3.33	3.33	13.33	7.73	10.00	8.08	3.33	2.04	5.00	3.33	0.00	0.00
32	myrhet	6.04	1.79	11.67	6.24	8.33	5.27	11.67	7.26	6.67	6.67	0.00	0.00	8.33	6.45	0.00	0.00	1.67	1.67
33	euppil	6.04	1.58	5.00	3.33	3.33	2.04	3.33	2.04	8.33	4.56	1.67	1.67	3.33	2.04	10.00	4.86	13.33	9.72
34	pleten	5.63	1.35	6.67	4.08	8.33	4.56	3.33	3.33	13.33	5.65	11.67	3.33	0.00	0.00	1.67	1.67	0.00	0.00
35	solpul	5.42	1.39	11.67	6.24	16.67	2.64	1.67	1.67	1.67	1.67	8.33	5.27	0.00	0.00	1.67	1.67	1.67	1.67
36	muhexp	5.42	2.26	18.33	16.33	5.00	3.33	1.67	1.67	10.00	6.12	3.33	3.33	3.33	2.04	0.00	0.00	1.67	1.67
37	cartom	5.42	1.68	8.33	4.56	20.00	9.35	0.00	0.00	1.67	1.67	8.33	4.56	1.67	1.67	1.67	1.67	1.67	1.67
38	smigla	5.21	1.48	11.67	6.24	16.67	5.89	3.33	2.04	3.33	2.04	6.67	4.86	0.00	0.00	0.00	0.00	0.00	0.00
39	xyrcar	4.17	1.52	5.00	3.33	8.33	6.45	0.00	0.00	5.00	5.00	13.33	7.73	0.00	0.00	1.67	1.67	0.00	0.00
40	magvir	4.17	1.03	10.00	1.67	6.67	3.12	0.00	0.00	3.33	2.04	8.33	5.27	0.00	0.00	3.33	3.33	1.67	1.67
41	pintae	3.75	1.15	1.67	1.67	5.00	5.00	5.00	3.33	0.00	0.00	8.33	3.73	8.33	5.27	0.00	0.00	1.67	1.67
42	liagra	3.33	1.46	3.33	3.33	6.67	4.08	0.00	0.00	10.00	10.00	0.00	0.00	0.00	0.00	1.67	1.67	5.00	3.33
43	gelsem	3.33	1.26	6.67	4.86	8.33	6.45	1.67	1.67	3.33	3.33	6.67	4.86	0.00	0.00	0.00	0.00	0.00	0.00
44	rheali	3.33	0.98	3.33	3.33	3.33	2.04	1.67	1.67	3.33	3.33	8.33	4.56	0.00	0.00	5.00	3.33	1.67	1.67
45	acerub	3.33	0.93	8.33	2.64	0.00	0.00	6.67	4.86	1.67	1.67	5.00	3.33	1.67	1.67	1.67	1.67	1.67	1.67
46	vaccor	3.33	1.15	8.33	2.64	3.33	2.04	0.00	0.00	13.33	6.77	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00
47	andsp	3.13	0.93	1.67	1.67	3.33	3.33	3.33	3.33	0.00	0.00	3.33	3.33	6.67	3.12	3.33	3.33	3.33	2.04
48	pinsp	3.12	0.98	5.00	2.04	3.33	3.33	0.00	0.00	0.00	0.00	5.00	3.33	1.67	1.67	8.33	5.27	1.67	1.67
49	rhoatl	2.92	1.57	8.33	8.33	8.33	8.33	0.00	0.00	0.00	0.00	5.00	5.00	1.67	1.67	0.00	0.00	0.00	0.00
50	rhesp	2.92	1.10	1.67	1.67	0.00	0.00	1.67	1.67	3.33	3.33	0.00	0.00	3.33	3.33	6.67	6.67	6.67	3.12
51	hypred	2.92	0.92	5.00	3.33	0.00	0.00	0.00	0.00	8.33	2.64	6.67	4.86	1.67	1.67	1.67	1.67	0.00	0.00
52	eupcap	2.71	1.13	0.00	0.00	0.00	0.00	5.00	2.04	0.00	0.00	0.00	0.00	1.67	1.67	5.00	5.00	10.00	6.67
53	pitgra	2.71	1.05	1.67	1.67	3.33	3.33	0.00	0.00	8.33	6.45	3.33	3.33	0.00	0.00	3.33	2.04	1.67	1.67
54	hypden	2.71	1.13	1.67	1.67	0.00	0.00	0.00	0.00	3.33	2.04	0.00	0.00	6.67	4.86	6.67	6.67	3.33	3.33
55	gorlas	2.29	0.79	3.33	3.33	1.67	1.67	0.00	0.00	3.33	3.33	1.67	1.67	5.00	3.33	3.33	2.04	0.00	0.00
56	clealn	2.08	1.11	6.67	6.67	0.00	0.00	1.67	1.67	0.00	0.00	3.33	3.33	0.00	0.00	5.00	5.00	0.00	0.00
57	zenpul	1.88	0.97	0.00	0.00	3.33	3.33	0.00	0.00	5.00	5.00	6.67	4.86	0.00	0.00	0.00	0.00	0.00	0.00

58	spopin	1.67	0.80	0.00	0.00	5.00	3.33	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	5.00	5.00	1.67	1.67
59	andvir	1.46	0.59	1.67	1.67	3.33	2.04	0.00	0.00	0.00	0.00	1.67	1.67	3.33	3.33	0.00	0.00	1.67	1.67
60	diomus	1.46	0.59	3.33	2.04	6.67	3.12	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00
61	kalcar	1.25	0.56	3.33	2.04	5.00	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
62	ileopa	1.25	0.48	1.67	1.67	0.00	0.00	0.00	0.00	1.67	1.67	3.33	2.04	3.33	2.04	0.00	0.00	0.00	0.00
63	xyramb	1.04	0.53	1.67	1.67	0.00	0.00	3.33	3.33	0.00	0.00	3.33	2.04	0.00	0.00	0.00	0.00	0.00	0.00
64	astlin	1.04	0.44	1.67	1.67	1.67	1.67	0.00	0.00	0.00	0.00	5.00	2.04	0.00	0.00	0.00	0.00	0.00	0.00
65	clesp	1.04	0.44	1.67	1.67	3.33	2.04	1.67	1.67	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00
66	arutec	0.83	0.50	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	3.33	3.33	0.00	0.00	1.67	1.67	0.00	0.00
67	cypsp	0.83	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.67	6.67	0.00	0.00	0.00	0.00	0.00	0.00
68	drocap	0.83	0.65	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	5.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00
69	ludalt	0.83	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.67	4.86	0.00	0.00	0.00	0.00
70	viosp	0.83	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33	2.04	0.00	0.00	3.33	3.33	0.00	0.00
71	lacanc	0.83	0.40	0.00	0.00	3.33	2.04	0.00	0.00	3.33	2.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
72	ilemyr	0.83	0.40	1.67	1.67	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67
73	euprot	0.63	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33	3.33	1.67	1.67	0.00	0.00
74	polcru	0.63	0.63	5.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
75	smisp	0.63	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33	3.33	1.67	1.67
76	astpal	0.62	0.35	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67
77	lobnut	0.62	0.35	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00
78	hypsta	0.62	0.35	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00
79	pinell	0.62	0.35	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67
80	symtin	0.62	0.35	1.67	1.67	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
81	utrjun	0.42	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33	3.33	0.00	0.00	0.00	0.00	0.00	0.00
82	eutten	0.42	0.29	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00
83	lacsp	0.42	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00	0.00	0.00
84	rhybre	0.42	0.29	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
85	alefar	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
86	erisp	0.21	0.21	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
87	eupalb	0.21	0.21	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
88	rhemar	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
89	rhepet	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67
90	sarfla	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00

91	sarpur	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
92	seycas	0.21	0.21	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
93	smibon	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
94	solsp	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67
95	solver	0.21	0.21	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
96	tarsp	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
97	zigden	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
98	hyphyp	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
99	lyolig	0.21	0.21	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	rhucop	0.21	0.21	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
101	ambart	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
102	amimus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
103	amppur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
104	astsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
105	cussp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
106	diclat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
107	drosp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
108	erigsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
109	gnaobt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
110	junsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
111	pansp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
112	plasp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
113	rhelut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
114	rhycil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
115	rhyfas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
116	rhyplu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
117	solfis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
118	solodo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
119	spisp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
120	vitsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
121	wooaer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
122	bacham	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
123	cascal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

124	hypsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
125	pinser	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
126	quesp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
127	rubsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
128	drobre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
129	ericom	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130	lescun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
131	polnan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
132	sabsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
133	smirot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
134	xyrbre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
135	diovir	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
136	liqsty	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
137	vacatt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

B. 2005

TREATMENT		**ALL**		**CB**		**CF**		**CHB**		**CM**		**F**		**HB**		**HF**		**HM**	
Rank	Species	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
1	dichsp	68.75	3.91	76.67	6.67	63.33	11.37	85.00	13.02	61.67	9.72	45.00	10.74	76.67	10.99	56.67	11.61	85.00	4.86
2	vaccra	63.54	3.38	68.33	7.17	81.67	5.53	58.33	9.50	53.33	12.53	70.00	10.74	60.00	6.67	46.67	12.53	70.00	5.65
3	rhysp	51.04	3.03	40.00	7.17	48.33	7.17	66.67	7.45	60.00	9.65	45.00	7.73	43.33	7.64	50.00	8.33	55.00	11.67
4	aroarb*+	49.37	4.50	71.67	7.26	75.00	13.94	46.67	11.96	56.67	12.47	56.67	12.75	23.33	10.00	36.67	6.77	28.33	9.35
5	pollut	48.75	3.60	45.00	4.25	65.00	8.08	56.67	8.50	43.33	8.50	40.00	11.61	36.67	12.53	45.00	14.81	58.33	9.86
6	ilegla+	45.00	4.08	55.00	14.09	55.00	9.72	41.67	11.79	48.33	14.77	61.67	10.74	38.33	10.07	35.00	10.34	25.00	7.91
7	gayfro*+	41.04	3.34	48.33	7.17	60.00	6.12	48.33	11.30	41.67	9.13	56.67	3.12	30.00	8.58	26.67	4.86	16.67	7.45
8	andcap	40.21	3.50	31.67	8.08	50.00	6.97	36.67	10.41	26.67	8.90	36.67	11.96	45.00	13.84	55.00	10.74	40.00	7.17
9	ptraqu	38.13	3.97	15.00	4.86	46.67	14.58	46.67	13.07	35.00	10.99	28.33	6.77	41.67	6.97	38.33	15.72	53.33	10.07
10	aristr*+	30.63	3.51	35.00	4.08	50.00	10.87	8.33	3.73	31.67	10.34	45.00	8.16	28.33	11.06	21.67	13.59	25.00	5.27
11	eupsp*+	30.63	4.30	36.67	14.34	25.00	7.45	40.00	12.47	25.00	7.91	10.00	4.86	41.67	17.28	26.67	15.46	40.00	13.79
12	perbor*+	27.50	3.48	43.33	10.99	40.00	8.08	35.00	4.86	28.33	7.73	51.67	8.90	3.33	2.04	8.33	2.64	10.00	3.12
13	schsch*	24.58	3.47	10.00	4.86	43.33	13.79	33.33	11.49	16.67	6.97	23.33	8.08	21.67	11.96	30.00	10.74	18.33	4.86
14	vacten*+	24.17	3.07	35.00	6.12	48.33	5.53	6.67	3.12	38.33	8.58	21.67	9.72	20.00	8.17	10.00	1.67	13.33	5.65
15	smilau	18.96	1.93	20.00	2.04	11.67	5.00	23.33	5.53	20.00	2.04	21.67	5.65	21.67	6.24	16.67	7.45	16.67	8.74

16	smigla	17.08	2.44	13.33	4.25	16.67	8.74	30.00	9.72	15.00	4.86	15.00	7.17	15.00	7.17	8.33	4.56	23.33	7.17
17	pinpal+	16.67	2.39	16.67	4.56	0.00	0.00	21.67	6.24	35.00	4.08	0.00	0.00	18.33	4.86	10.00	4.86	31.67	4.86
18	xyrsp+	15.00	2.45	16.67	8.74	26.67	7.64	10.00	4.08	15.00	7.64	25.00	9.86	11.67	5.65	10.00	4.86	5.00	2.04
19	rhesp+	14.17	2.24	8.33	5.27	6.67	4.86	18.33	7.17	11.67	6.24	13.33	6.77	13.33	5.00	13.33	6.24	28.33	7.73
20	lyomar+	13.96	2.79	10.00	4.86	28.33	7.73	5.00	3.33	23.33	13.54	13.33	5.65	18.33	12.19	6.67	3.12	6.67	3.12
21	ilecor	13.75	1.92	18.33	6.12	16.67	4.56	8.33	3.73	8.33	6.45	23.33	3.12	13.33	7.73	10.00	6.12	11.67	4.25
22	irisp	13.54	2.38	13.33	11.37	21.67	6.24	16.67	5.89	15.00	8.08	8.33	4.56	10.00	6.12	10.00	6.67	13.33	6.24
23	lyoluc	13.12	2.88	11.67	6.24	5.00	3.33	5.00	5.00	18.33	4.86	36.67	13.59	6.67	3.12	16.67	11.49	5.00	3.33
24	gaydum	12.29	1.69	16.67	3.73	20.00	5.65	6.67	3.12	20.00	4.25	18.33	4.86	8.33	3.73	5.00	3.33	3.33	3.33
25	laccar	11.87	2.98	21.67	14.81	6.67	4.86	21.67	12.80	21.67	9.72	6.67	4.08	11.67	6.24	1.67	1.67	3.33	2.04
26	cypsp	10.83	2.80	16.67	10.21	11.67	8.17	11.67	11.67	21.67	10.41	13.33	7.73	6.67	6.67	1.67	1.67	3.33	3.33
27	myrcer	10.83	1.77	11.67	4.25	18.33	5.53	6.67	3.12	5.00	3.33	13.33	4.25	10.00	8.08	5.00	3.33	16.67	5.89
28	carodo	10.83	2.45	8.33	6.45	30.00	9.35	1.67	1.67	5.00	3.33	23.33	10.34	5.00	3.33	5.00	3.33	8.33	3.73
29	woovir	10.21	2.41	18.33	9.28	3.33	2.04	15.00	10.00	16.67	5.89	11.67	9.72	8.33	6.45	1.67	1.67	6.67	4.86
30	muhexp	9.17	2.23	23.33	7.64	18.33	8.90	0.00	0.00	18.33	5.53	10.00	6.67	0.00	0.00	3.33	3.33	0.00	0.00
31	cyrrac	8.75	2.83	5.00	3.33	0.00	0.00	3.33	2.04	8.33	3.73	15.00	8.08	0.00	0.00	31.67	17.95	6.67	4.08
32	andsp	8.12	1.54	18.33	7.17	6.67	3.12	3.33	2.04	5.00	3.33	8.33	5.27	11.67	2.04	5.00	3.33	6.67	4.86
33	osmcin	7.92	1.55	8.33	5.27	8.33	3.73	8.33	2.64	11.67	4.25	5.00	5.00	11.67	7.73	5.00	3.33	5.00	3.33
34	pinsp	7.92	1.86	3.33	2.04	16.67	9.50	5.00	3.33	3.33	2.04	10.00	6.67	6.67	4.08	13.33	5.65	5.00	5.00
35	rheali	7.71	1.64	18.33	10.00	8.33	3.73	3.33	2.04	11.67	4.25	8.33	3.73	3.33	2.04	3.33	2.04	5.00	2.04
36	rhepet	6.46	1.21	5.00	2.04	8.33	5.27	5.00	3.33	3.33	2.04	3.33	2.04	8.33	3.73	8.33	3.73	10.00	4.86
37	solpul	6.46	1.59	15.00	8.90	15.00	3.12	3.33	2.04	6.67	4.86	5.00	3.33	1.67	1.67	0.00	0.00	5.00	3.33
38	rhenas	5.83	1.64	1.67	1.67	3.33	3.33	15.00	8.08	1.67	1.67	3.33	3.33	11.67	6.24	1.67	1.67	8.33	5.27
39	myrhet	5.62	1.24	8.33	5.27	8.33	2.64	10.00	4.86	1.67	1.67	3.33	2.04	6.67	4.86	1.67	1.67	5.00	3.33
40	acerub	5.21	1.10	8.33	3.73	6.67	3.12	5.00	2.04	15.00	4.08	1.67	1.67	3.33	2.04	0.00	0.00	1.67	1.67
41	lacanc	5.21	1.36	5.00	2.04	6.67	3.12	1.67	1.67	3.33	2.04	0.00	0.00	11.67	7.73	8.33	5.27	5.00	3.33
42	hypred	5.00	1.68	8.33	6.45	3.33	2.04	1.67	1.67	10.00	10.00	3.33	3.33	5.00	5.00	3.33	3.33	5.00	3.33
43	gelsem	5.00	1.54	8.33	4.56	13.33	7.73	1.67	1.67	8.33	6.45	6.67	4.08	1.67	1.67	0.00	0.00	0.00	0.00
44	pleten	4.79	1.15	11.67	4.25	5.00	3.33	0.00	0.00	10.00	4.86	6.67	3.12	0.00	0.00	0.00	0.00	5.00	2.04
45	cartom	4.58	1.15	5.00	5.00	13.33	4.25	3.33	2.04	5.00	3.33	1.67	1.67	3.33	2.04	3.33	3.33	1.67	1.67
46	rhoatl	4.37	2.21	11.67	11.67	13.33	13.33	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	0.00	0.00	3.33	3.33
47	eupcap	3.96	1.19	0.00	0.00	0.00	0.00	10.00	4.86	3.33	3.33	1.67	1.67	6.67	4.08	5.00	5.00	5.00	3.33
48	magvir	3.75	0.94	8.33	4.56	6.67	3.12	3.33	2.04	5.00	3.33	1.67	1.67	0.00	0.00	3.33	2.04	1.67	1.67

49	rhyplu	3.75	0.84	3.33	2.04	5.00	3.33	1.67	1.67	5.00	3.33	5.00	2.04	1.67	1.67	8.33	2.64	0.00	0.00
50	andvir	3.54	0.89	5.00	3.33	5.00	2.04	3.33	3.33	8.33	3.73	5.00	2.04	1.67	1.67	0.00	0.00	0.00	0.00
51	pansp	3.33	1.02	5.00	3.33	0.00	0.00	3.33	2.04	1.67	1.67	1.67	1.67	5.00	5.00	5.00	5.00	5.00	2.04
52	poasp	3.12	0.88	1.67	1.67	6.67	3.12	3.33	3.33	3.33	2.04	3.33	3.33	1.67	1.67	1.67	1.67	3.33	3.33
53	gorlas	3.12	1.02	3.33	2.04	10.00	6.12	3.33	2.04	1.67	1.67	5.00	3.33	0.00	0.00	0.00	0.00	1.67	1.67
54	liagra	2.92	1.21	3.33	3.33	1.67	1.67	0.00	0.00	10.00	8.08	1.67	1.67	1.67	1.67	0.00	0.00	5.00	3.33
55	drocap	2.92	0.82	5.00	2.04	0.00	0.00	1.67	1.67	1.67	1.67	3.33	3.33	5.00	3.33	5.00	3.33	1.67	1.67
56	vaccor	2.92	0.82	1.67	1.67	3.33	2.04	3.33	2.04	5.00	2.04	1.67	1.67	1.67	1.67	0.00	0.00	6.67	4.86
57	pintae	2.50	0.74	3.33	3.33	5.00	3.33	1.67	1.67	0.00	0.00	3.33	2.04	3.33	2.04	1.67	1.67	1.67	1.67
58	arutec	2.08	0.88	0.00	0.00	5.00	5.00	1.67	1.67	0.00	0.00	5.00	3.33	0.00	0.00	3.33	3.33	1.67	1.67
59	carsp	2.08	1.15	3.33	3.33	0.00	0.00	8.33	8.33	1.67	1.67	1.67	1.67	1.67	1.67	0.00	0.00	0.00	0.00
60	ambart	2.08	0.72	0.00	0.00	0.00	0.00	8.33	0.00	0.00	0.00	0.00	0.00	3.33	3.33	5.00	3.33	0.00	0.00
61	diomus	1.87	0.70	0.00	0.00	8.33	3.73	0.00	0.00	1.67	1.67	5.00	2.04	0.00	0.00	0.00	0.00	0.00	0.00
62	tarsp	1.87	0.63	0.00	0.00	1.67	1.67	5.00	2.04	0.00	0.00	0.00	0.00	3.33	2.04	3.33	3.33	1.67	1.67
63	xyrcar	1.67	0.80	0.00	0.00	1.67	1.67	0.00	0.00	5.00	5.00	5.00	3.33	0.00	0.00	0.00	0.00	1.67	1.67
64	clealn	1.46	0.78	5.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	1.67	1.67	3.33	3.33	0.00	0.00
65	hypden	1.46	0.66	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	3.33	3.33	5.00	3.33	1.67	1.67	0.00	0.00
66	pitgra	1.46	0.78	0.00	0.00	1.67	1.67	0.00	0.00	5.00	5.00	3.33	3.33	0.00	0.00	0.00	0.00	1.67	1.67
67	ileopa	1.46	0.59	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	8.33	2.64	0.00	0.00	1.67	1.67
68	smirot	1.46	0.59	1.67	1.67	0.00	0.00	0.00	0.00	6.67	3.12	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00
69	vacatt	1.25	0.64	5.00	3.33	1.67	1.67	0.00	0.00	3.33	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	spisp	1.25	0.70	1.67	1.67	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67	5.00	5.00	0.00	0.00	0.00	0.00
71	symtin	1.25	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33	2.04	5.00	5.00	1.67	1.67
72	kalcar	1.25	0.48	1.67	1.67	3.33	2.04	1.67	1.67	1.67	1.67	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00
73	ericom	1.25	0.48	3.33	2.04	1.67	1.67	1.67	1.67	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67
74	rhemar	1.25	0.48	0.00	0.00	0.00	0.00	3.33	2.04	3.33	2.04	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67
75	zenpul	1.04	0.61	0.00	0.00	0.00	0.00	0.00	0.00	5.00	3.33	3.33	3.33	0.00	0.00	0.00	0.00	0.00	0.00
76	spopin	1.04	0.53	3.33	3.33	3.33	2.04	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
77	utrjun	1.04	0.53	1.67	1.67	0.00	0.00	0.00	0.00	3.33	3.33	1.67	1.67	0.00	0.00	0.00	0.00	1.67	1.67
78	xyramb	1.04	0.44	0.00	0.00	0.00	0.00	1.67	1.67	3.33	2.04	0.00	0.00	0.00	0.00	0.00	0.00	3.33	2.04
79	hypsta	0.83	0.50	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	5.00	3.33	0.00	0.00	0.00	0.00
80	rhycil	0.83	0.50	0.00	0.00	3.33	3.33	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67
81	rhyfas	0.83	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.67	6.67	0.00	0.00

82	sarfla	0.83	0.50	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	5.00	3.33	0.00	0.00	0.00	0.00	0.00	0.00
83	solsp	0.83	0.40	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67	1.67	1.67	1.67	1.67	0.00	0.00
84	wooaer	0.83	0.40	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00
85	lobnut	0.63	0.46	0.00	0.00	0.00	0.00	0.00	0.00	3.33	3.33	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
86	polcru	0.63	0.46	3.33	3.33	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
87	smisp	0.62	0.35	0.00	0.00	0.00	0.00	3.33	2.04	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
88	hypsp	0.42	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33	3.33	0.00	0.00
89	rhucop	0.42	0.42	0.00	0.00	3.33	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	ilemyr	0.42	0.29	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00
91	rubsp	0.42	0.29	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67
92	alefar	0.42	0.29	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
93	clesp	0.42	0.29	3.33	2.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
94	drobre	0.42	0.29	0.00	0.00	0.00	0.00	3.33	2.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
95	gnaobt	0.42	0.29	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
96	lescun	0.42	0.29	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67
97	polnan	0.42	0.29	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
98	viosp	0.42	0.29	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
99	zigden	0.42	0.29	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
100	pinser	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00
101	quesp	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
102	amimus	0.21	0.21	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
103	astlin	0.21	0.21	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
104	diclat	0.21	0.21	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
105	erisp	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67
106	plasp	0.21	0.21	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
107	rhelut	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
108	sarpur	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00
109	vitsp	0.21	0.21	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
110	bacham	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
111	cascal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
112	amppur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
113	astsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
114	cussp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

115	drosp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
116	erigsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
117	junsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
118	solfis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
119	solodo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
120	diovir	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
121	hyphyp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
122	liqsty	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
123	lyolig	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
124	pinell	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
125	astpal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
126	eupalb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
127	euppil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
128	euprot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
129	eutten	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130	lacsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
131	ludalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
132	rhybre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
133	sabsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
134	seycas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
135	smibon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
136	solver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
137	xyrbre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

C. 2006

TREATMENT		ALL		CB		CF		CHB		CM		F		HB		HF		HM	
Rank	Species	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
1	dichsp	65.92	3.85	68.33	4.86	73.33	10.00	65.00	13.02	65.00	10.00	52.33	9.57	65.00	16.54	65.00	15.23	73.33	9.65
2	vaccra	61.83	3.81	73.33	6.12	83.33	5.89	55.00	14.09	45.00	9.35	68.00	10.82	51.67	10.67	45.00	10.07	73.33	8.50
3	andcap*+	59.25	4.34	36.67	3.33	40.00	12.19	90.00	4.08	36.67	5.65	45.67	13.36	75.00	9.50	75.00	8.74	75.00	9.86
4	rhysp	52.58	3.80	31.67	6.12	50.00	7.45	68.33	11.61	58.33	13.18	45.67	12.56	48.33	4.86	61.67	9.35	56.67	15.23
5	aroarb*+	46.79	4.68	70.00	11.06	68.33	15.46	35.00	15.00	56.67	7.17	62.67	13.10	23.33	9.28	25.00	5.89	33.33	10.21
6	ilegla*+	46.42	3.60	56.67	8.90	51.67	8.08	36.67	3.33	58.33	17.28	63.00	13.16	35.00	1.67	40.00	7.17	30.00	7.73

7	gayfro*+	45.75	3.62	51.67	6.12	68.33	6.12	45.00	11.67	43.33	11.61	61.00	10.42	38.33	8.58	30.00	9.35	28.33	7.73
8	ptraqu	40.21	3.88	23.33	8.08	48.33	13.54	50.00	15.37	35.00	10.00	31.67	11.90	41.67	7.91	38.33	10.74	53.33	9.35
9	schsch	36.17	3.21	31.67	9.28	31.67	14.53	46.67	8.98	30.00	7.73	32.67	11.80	31.67	8.08	48.33	6.12	36.67	5.65
10	aristr*+	35.83	3.74	46.67	8.16	66.67	7.91	10.00	3.12	33.33	10.87	50.00	10.87	30.00	9.35	23.33	7.17	26.67	4.86
11	pollut+	34.21	3.56	36.67	8.98	30.00	7.73	51.67	9.65	21.67	10.41	13.67	4.16	35.00	10.99	40.00	13.54	45.00	7.73
12	xyrsp	33.21	3.68	28.33	10.07	45.00	10.74	33.33	12.36	28.33	5.65	49.00	14.28	26.67	8.50	28.33	10.41	26.67	11.61
13	smilau	30.71	3.43	31.67	11.90	13.33	5.65	48.33	12.19	31.67	10.34	40.67	8.23	31.67	11.90	26.67	4.08	21.67	7.73
14	perbor*+	28.71	3.63	55.00	11.96	36.67	6.77	21.67	2.04	33.33	11.49	48.00	9.71	10.00	4.08	16.67	4.56	8.33	6.45
15	eupsp*+	23.29	3.21	28.33	7.26	11.67	6.24	40.00	6.12	16.67	2.64	11.33	7.40	18.33	7.64	13.33	9.35	46.67	11.96
16	gaydum*+	20.67	2.51	16.67	4.56	40.00	7.17	3.33	2.04	28.33	4.25	33.67	9.36	15.00	4.08	13.33	3.33	15.00	4.86
17	rhepet	20.04	2.95	21.67	5.65	18.33	8.50	30.00	16.37	23.33	8.50	13.67	6.72	11.67	6.24	21.67	7.73	20.00	5.65
18	laccar	18.58	3.70	16.67	11.49	6.67	6.67	26.67	14.77	31.67	11.30	17.00	11.19	20.00	11.37	16.67	10.54	13.33	8.58
19	lyomar	16.08	2.99	20.00	11.96	31.67	10.99	3.33	2.04	18.33	8.50	10.33	4.06	11.67	8.17	20.00	10.74	13.33	5.65
20	vacten*+	15.33	2.33	16.67	2.64	41.67	4.56	5.00	5.00	13.33	7.73	21.00	4.64	10.00	3.12	10.00	4.08	5.00	3.33
21	lyoluc	15.17	3.51	18.33	6.67	6.67	4.86	3.33	3.33	21.67	8.16	38.00	14.56	6.67	4.86	18.33	18.33	8.33	3.73
22	irisp	15.00	2.32	13.33	5.65	25.00	9.50	6.67	4.08	20.00	5.65	18.33	8.08	5.00	3.33	15.00	9.28	16.67	2.64
23	cypsp	14.79	2.54	13.33	9.35	11.67	5.65	6.67	3.12	31.67	8.50	23.33	8.90	13.33	5.65	10.00	6.67	8.33	4.56
24	rhenas	14.75	3.57	5.00	3.33	3.33	3.33	28.33	13.33	8.33	6.45	8.00	8.00	26.67	10.34	15.00	9.28	23.33	17.76
25	astsp	14.62	2.44	8.33	4.56	18.33	10.99	20.00	7.73	6.67	6.67	17.00	5.78	16.67	4.56	15.00	6.12	15.00	9.28
26	ilecor	14.42	1.98	16.67	5.89	23.33	8.08	8.33	3.73	15.00	6.12	17.00	5.15	13.33	7.73	11.67	4.25	10.00	3.12
27	andvir	14.25	2.20	10.00	3.12	26.67	8.90	10.00	4.86	10.00	4.86	19.00	6.66	10.00	4.86	16.67	9.50	11.67	4.25
28	pinpal	14.21	1.77	20.00	5.65	5.00	3.33	16.67	5.27	23.33	3.12	3.67	2.26	13.33	4.25	10.00	4.08	21.67	5.00
29	andsp	13.96	2.30	8.33	4.56	25.00	9.13	10.00	6.67	11.67	6.24	11.67	7.26	15.00	4.08	3.33	2.04	26.67	6.12
30	woovir	12.50	2.50	11.67	6.24	8.33	6.45	23.33	11.61	10.00	4.86	15.00	9.28	11.67	7.73	3.33	2.04	16.67	5.89
31	smigla	12.33	1.66	13.33	4.25	21.67	6.24	15.00	6.12	10.00	4.86	8.67	2.66	8.33	2.64	13.33	4.25	8.33	5.27
32	euppil	12.29	2.91	0.00	0.00	8.33	6.45	23.33	6.67	10.00	8.08	1.67	1.67	28.33	15.72	16.67	6.97	10.00	6.12
33	rhyplu	11.08	1.64	8.33	2.64	15.00	6.67	8.33	2.64	13.33	3.33	12.00	3.27	10.00	6.12	20.00	6.24	1.67	1.67
34	cyrrac	10.42	2.61	5.00	3.33	1.67	1.67	5.00	3.33	13.33	6.24	15.00	10.00	1.67	1.67	25.00	13.94	16.67	6.97
35	osmcin	10.21	1.85	6.67	6.67	8.33	3.73	16.67	6.97	11.67	6.24	8.33	3.73	11.67	5.65	6.67	4.86	11.67	5.65
36	myrhet	9.42	1.84	11.67	5.65	8.33	2.64	15.00	7.64	16.67	6.97	8.67	4.58	11.67	5.65	3.33	3.33	0.00	0.00
37	solpul	9.21	1.93	10.00	4.86	15.00	7.17	5.00	3.33	6.67	6.67	20.33	6.63	6.67	4.86	5.00	3.33	5.00	5.00
38	myrcer	9.04	1.57	5.00	5.00	15.00	5.53	8.33	6.45	1.67	1.67	14.00	3.56	3.33	2.04	8.33	3.73	16.67	2.64
39	muhexp	8.87	1.96	16.67	5.89	16.67	6.97	3.33	2.04	13.33	6.77	12.67	7.77	0.00	0.00	6.67	4.86	1.67	1.67

40	cartom	8.75	2.81	5.00	3.33	35.00	14.04	0.00	0.00	5.00	5.00	11.67	11.67	3.33	3.33	3.33	3.33	6.67	3.12
41	rheali	7.79	1.46	10.00	4.86	6.67	4.86	3.33	2.04	10.00	4.08	14.00	6.36	5.00	2.04	6.67	4.86	6.67	3.12
42	lacanc	7.08	1.70	5.00	2.04	6.67	4.86	1.67	1.67	8.33	6.45	1.67	1.67	13.33	5.65	11.67	4.25	8.33	8.33
43	hypred	6.87	2.29	10.00	6.67	0.00	0.00	6.67	6.67	13.33	11.37	11.67	9.72	3.33	3.33	6.67	6.67	3.33	2.04
44	liagra	6.71	2.32	5.00	5.00	3.33	3.33	0.00	0.00	13.33	9.35	5.33	3.43	3.33	3.33	10.00	10.00	13.33	11.37
45	pleten	6.54	1.58	13.33	4.25	11.67	7.73	0.00	0.00	11.67	5.00	14.00	3.56	0.00	0.00	1.67	1.67	0.00	0.00
46	carodo	6.46	1.67	10.00	4.86	15.00	9.28	3.33	3.33	5.00	2.04	8.33	6.45	3.33	3.33	3.33	2.04	3.33	2.04
47	poasp	6.46	2.12	10.00	8.08	8.33	6.45	1.67	1.67	11.67	11.67	3.33	2.04	5.00	2.04	1.67	1.67	10.00	8.08
48	gelsem	5.83	1.47	10.00	4.86	10.00	6.67	5.00	2.04	8.33	6.45	8.33	3.73	1.67	1.67	0.00	0.00	3.33	3.33
49	magvir	5.62	1.13	15.00	4.86	1.67	1.67	6.67	3.12	8.33	3.73	1.67	1.67	1.67	1.67	5.00	2.04	5.00	2.04
50	rhoatl	5.42	2.18	10.00	10.00	11.67	11.67	6.67	6.67	5.00	5.00	3.33	3.33	1.67	1.67	0.00	0.00	5.00	5.00
51	eupalb	5.00	1.11	5.00	2.04	3.33	2.04	10.00	4.86	0.00	0.00	1.67	1.67	6.67	4.86	3.33	2.04	10.00	3.12
52	pinsp	4.58	1.15	5.00	2.04	0.00	0.00	8.33	3.73	3.33	3.33	10.00	4.08	1.67	1.67	5.00	5.00	3.33	3.33
53	pitgra	4.58	1.63	1.67	1.67	5.00	3.33	0.00	0.00	10.00	8.08	6.67	4.86	0.00	0.00	1.67	1.67	11.67	8.17
54	acerub	4.42	1.20	11.67	6.24	0.00	0.00	3.33	2.04	10.00	4.86	7.00	1.78	0.00	0.00	1.67	1.67	1.67	1.67
55	solfis	4.37	1.08	0.00	0.00	0.00	0.00	11.67	2.04	1.67	1.67	0.00	0.00	8.33	5.27	6.67	3.12	6.67	3.12
56	pansp	4.37	2.05	0.00	0.00	0.00	0.00	6.67	6.67	5.00	2.04	1.67	1.67	11.67	11.67	10.00	10.00	0.00	0.00
57	vaccor	4.17	1.27	8.33	5.27	1.67	1.67	1.67	1.67	15.00	6.12	1.67	1.67	3.33	2.04	1.67	1.67	0.00	0.00
58	carsp	2.96	0.83	1.67	1.67	5.00	3.33	0.00	0.00	3.33	2.04	2.00	2.00	3.33	2.04	3.33	3.33	5.00	3.33
59	amppur	2.83	1.12	0.00	0.00	1.67	1.67	1.67	1.67	5.00	5.00	6.00	6.00	3.33	3.33	5.00	3.33	0.00	0.00
60	clealn	2.71	0.91	3.33	3.33	0.00	0.00	0.00	0.00	5.00	3.33	3.33	3.33	5.00	3.33	3.33	3.33	1.67	1.67
61	eupcap	2.29	0.99	0.00	0.00	1.67	1.67	6.67	6.67	0.00	0.00	0.00	0.00	1.67	1.67	3.33	2.04	5.00	3.33
62	arutec	2.29	0.94	6.67	6.67	1.67	1.67	1.67	1.67	3.33	2.04	1.67	1.67	1.67	1.67	0.00	0.00	1.67	1.67
63	lyolig	1.87	0.56	1.67	1.67	3.33	2.04	0.00	0.00	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	3.33	2.04
64	junsp	1.67	0.74	3.33	3.33	0.00	0.00	1.67	1.67	5.00	3.33	0.00	0.00	0.00	0.00	3.33	3.33	0.00	0.00
65	lobnut	1.67	0.85	0.00	0.00	0.00	0.00	0.00	0.00	8.33	5.27	1.67	1.67	0.00	0.00	3.33	3.33	0.00	0.00
66	diomus	1.67	0.68	5.00	3.33	3.33	2.04	0.00	0.00	3.33	3.33	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00
67	ileopa	1.67	0.53	1.67	1.67	1.67	1.67	1.67	1.67	3.33	2.04	0.00	0.00	3.33	2.04	1.67	1.67	0.00	0.00
68	vacatt	1.46	0.51	1.67	1.67	3.33	2.04	1.67	1.67	1.67	1.67	3.33	2.04	0.00	0.00	0.00	0.00	0.00	0.00
69	zenpul	1.25	0.70	0.00	0.00	0.00	0.00	0.00	0.00	6.67	4.08	3.33	3.33	0.00	0.00	0.00	0.00	0.00	0.00
70	gorlas	1.25	0.56	0.00	0.00	3.33	2.04	0.00	0.00	0.00	0.00	5.00	3.33	0.00	0.00	1.67	1.67	0.00	0.00
71	kalcar	1.25	0.70	0.00	0.00	1.67	1.67	5.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	1.67	1.67
72	pinell	1.25	0.70	0.00	0.00	5.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	1.67	1.67	1.67	1.67

73	drocap	1.04	0.53	0.00	0.00	0.00	0.00	5.00	3.33	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	1.67	1.67
74	diovir	0.83	0.50	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	3.33	3.33	0.00	0.00	1.67	1.67	0.00	0.00
75	eutten	0.83	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.67	6.67	0.00	0.00	0.00	0.00
76	rubsp	0.83	0.40	0.00	0.00	0.00	0.00	3.33	2.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33	2.04
77	polcru	0.83	0.40	1.67	1.67	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
78	wooaer	0.83	0.40	0.00	0.00	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67
79	drobre	0.63	0.46	0.00	0.00	0.00	0.00	3.33	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67
80	viosp	0.62	0.35	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67	0.00	0.00
81	plasp	0.42	0.42	3.33	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
82	solodo	0.42	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33	3.33
83	bacham	0.42	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00
84	hypden	0.42	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33	2.04
85	hypsta	0.42	0.29	0.00	0.00	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
86	drosp	0.42	0.29	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00
87	erigsp	0.42	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	1.67	1.67
88	ludalt	0.42	0.29	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00
89	sarfla	0.42	0.29	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00
90	zigden	0.42	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	1.67	1.67	0.00	0.00
91	sarpur	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00
92	cascal	0.21	0.21	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
93	ilemyr	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
94	rhucop	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
95	ambart	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67
96	amimus	0.21	0.21	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
97	astlin	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
98	clesp	0.21	0.21	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
99	cussp	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00
100	gnaobt	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00
101	polnan	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67
102	rhemar	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
103	rhycil	0.21	0.21	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
104	sabsp	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
105	smisp	0.21	0.21	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

106	spopin	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	0.00	0.00
107	hypsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
108	hyphyp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
109	liqsty	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
110	pinser	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
111	pintae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
112	quesp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
113	symtin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
114	alefar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
115	astpal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
116	diclat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
117	erisp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
118	ericom	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
119	euprot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
120	lacsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
121	lescun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
122	rhelut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
123	rhesp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
124	rhybre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
125	rhyfas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
126	seycas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
127	smibon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
128	smirot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
129	solsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130	solver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
131	spisp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
132	tarsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
133	utrjun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
134	vitsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
135	xyramb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
136	xyrbre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
137	xyrcar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix PL1 (A-E). Summary of soil chemistry, soil texture, and tree density and basal area for reference and plantation plots.

A.

plot	stand	age	CEC	Ksat	Mgsat	Casat	pH	OM	K	Mg	Ca	series
C1_53	1	70	5.91	0.933	6.623	15.58	3.9	0.4	21	46.25	182	Ln
C1_54	1	70	4.143	0.858	6.613	20.42	4.175	0.475	14	32.75	171.5	BmB
C1_57	1	70	10.528	0.705	5.885	12.575	3.575	0.625	26.5	74	269	Ln
C1_58	1	70	4.863	0.553	6.043	18.673	4.033	0.633	11.667	35.333	182	FoA
C1_59	1	70	6.825	0.98	5.53	14.118	3.725	0.1	26	45.25	192	Bm
C1_60	1	70	.	.	.	.	.	.	.	.	.	KuB
C2_53	1	70	6.398	0.648	6.285	13.263	3.725	0.3	16.25	48.25	171.5	On
C2_54	1	70	6.23	0.673	6.025	19.413	4.075	0.55	15.25	42	239	BmB
C2_56	1	70	9.793	0.825	6.993	19.045	4.15	0.625	31	80.75	370	Ln
C2_57	1	70	26.015	0.785	5.843	13.71	3.6	6.05	78.75	179.25	698	Ln
C2_58	1	70	3.39	1.318	10.255	30.06	4.775	0.425	13.5	35.5	173.25	BmB
C2_59	1	70	3.398	0.93	9.96	30.693	4.85	0.45	11.75	39	209.25	BmB
C2_62	1	70	6.38	0.773	6.805	23.145	4.325	0.4	20	52.75	299	KuB
C2_63	1	70	6.62	0.74	6.183	17.7	4.05	0.125	19.25	48	235.5	KuB
C2_64	1	70	.	.	.	.	.	.	.	.	.	KuB
C3_51	1	70	5.33	0.815	5.893	14.523	3.8	0.25	16.75	37.75	154.75	Ln
C3_52	1	70	3.355	0.655	8.248	25.663	4.475	0.425	9.75	33.25	175.25	BmB
C3_54	1	70	15.18	0.285	4.615	33.275	4.525	0.375	16.75	84	1009	Ln
C3_55	1	70	5.228	1.268	5.908	17.358	4.05	0.45	22.5	34.75	188	BmB
C4_53	1	70	6.055	0.978	6.835	14.233	3.825	0.125	22.75	49	170.75	On
C4_54	1	70	4.085	1.093	6.138	18.15	4.025	0.475	17.25	29.75	147	ApB
C4_56	1	70	6.615	0.883	6.065	12.735	3.65	0.325	22.75	48	168.5	BmB
C4_57	1	70	4.893	1.1	5.563	15.303	3.85	0.35	21	32.75	149.25	Ln
C4_58	1	70	3.888	1.245	6.308	19.338	4.15	0.85	16.25	25.75	149.5	FoA
C4_59	1	70	6.253	1.058	4.708	15.923	3.8	0.275	25.5	34.25	199.5	BmB
C4_62	1	70	3.983	1.728	5.503	12.983	3.8	0.35	27	25.75	104.75	Wo
C5_54	1	70	7.73	0.778	6.188	13.82	3.75	0.5	22	57.5	213.5	On

Appendix PL1 (continued)

B.

plot	stand	age	CEC	Ksat	Mgsat	Casat	pH	OM	K	Mg	Ca	series
C5_55	1	70	5.895	0.848	5.28	18.415	4.025	0.275	18.25	36	228.5	BmB
C5_57	1	70	7.305	2.12	5.908	9.463	3.5	0.625	25.75	45.5	159.5	BmB
C5_58	1	70	4.46	0.203	5.2	11.778	3.65	0.675	3.75	27.75	104.75	KuB
C5_59	1	70	3.88	0.79	5.653	13.255	3.65	0.25	12.5	25.75	103	BmB
C5_60	1	70	7.038	0.688	5.098	14.693	3.65	0.425	19	42.5	205	BmB
C5_62	1	70	8.89	0.778	6.438	10.403	3.475	0.475	27	67.25	186.25	Ln
C5_63	1	70	5.625	0.673	6.065	16.52	3.9	0.45	16.25	40.75	187.25	BmB
C6_51	1	70	4.2	1.193	5.315	14.348	3.8	0.375	18.25	26	118.75	BmB
C6_52	1	70	4.778	1.095	5.235	16.373	3.975	0.425	20.25	29.75	157.75	FoA
C6_54	1	70	6.45	0.91	6.98	14.96	3.9	0.5	23	54	193	Ln
C6_55	1	70	4.918	1.225	6.473	17.713	4.075	0.5	21	37.5	168	Fo
C7_52	1	70	8.408	1.125	8.52	12.033	3.875	0.55	37	86.5	201.75	Ln
C7_53	1	70	7.453	1.25	7.05	20.485	3.45	0.55	40.25	66.25	226.25	KuB
P1	2		28.925	0.25	0.675	0.55	3.8	5.75	57	45.75	63.25	Wo
P10	2		3.95	6.375	8.7	14.875	4.075	0.675	47.25	27.25	75.75	On
P11	2		9.475	1.025	1.225	3.2	4.4	1.325	62.5	25.5	112	On
P2	2		23	0.3	0.575	1.25	3.825	3.2	56.75	33.5	122.75	Wo
P3	2		6.45	1.2	2.225	5.025	4	0.975	49	29	105.75	BmB
P31	2	41	13.8	0.225	1.1	3	4.5	1.8	23.5	36.5	163.25	On
P33	2	33	12.875	0.25	1.225	3	4.45	1.375	23	36.25	153.5	On
P4	2		17.4	0.325	1.625	1.65	3.825	1.8	48	69.5	115	Ln
P42	2	20	7.4	0.3	2.5	12.65	4.575	1.2	20.75	42.75	354.25	BmB
P43	2	16	8.4	0.5	2.425	8.1	4.875	1.175	30.25	47.25	267	BmB
P46	2	17	7.7	0.175	1.8	4.35	4.625	1.125	10.75	33.25	136.75	BmB
P5	2		11.125	0.675	0.875	1.25	4.525	2.55	57.75	24	55.5	Wo
P53	2	32	14.975	0.25	1.875	2.125	3.825	2.9	29	58	119.5	Ln
P55	2	30	14.425	0.2	1.825	1.875	4	1.875	26.5	70.25	118.25	Ln

*

Appendix PL1 (continued)

C.

plot	stand	age	CEC	Ksat	Mgsat	Casat	pH	OM	K	Mg	Ca	series
P6	2		8.625	0.65	2.225	6.825	4.075	1.1	43	46	234.25	Ln
P61	2	41	11.725	0.575	1.425	3.625	4.35	1.625	51.75	38.75	160.25	BmB
P66	2	31	3.725	1.425	2.875	7.575	4.55	0.75	41.5	25.75	113.75	BmB
P67	2	68	6.625	1.125	3.225	9.525	4.175	1.375	58.25	51.25	251	BmB
P7	2		16.2	0.375	1.45	3.65	3.95	1.8	46.75	56	238	BmB
P72	2	22	14.75	0.6	1.4	1.675	3.725	2.2	39.75	34.25	65	Ln
P74	2	26	14.75	0.25	2.025	4.5	3.95	1.95	30.25	70.75	242.75	KuB
P77	2	26	17.925	0.6	2.275	5.45	4.175	2.775	87.5	96.25	373.5	Ln
P78	2	6	17.3	0.35	1.7	2.75	3.925	2.425	47	71	184	Ln
P79	2	17	5.825	0.2	2.125	5.425	4.1	0.7	8.25	28.5	119.25	Ln
P8	2		11.725	0.575	1.8	3.85	3.975	1.4	47	43.5	150.75	KuB
P81	2	25	4.225	3.025	7.875	17.025	4.025	0.575	16	20.25	89	KuB
P82	2	25	5.525	0.675	3.675	9.65	4.175	0.45	11	26	120.75	KuB
P83	2	29	6.025	0.3	2.175	8.5	4.3	0.875	11.75	29.75	196.5	KuB
P9	2		15.15	0.35	0.85	1.75	4.2	1.9	42	30	103.25	Wo

Appendix PL1 (continued)

D.

plot	clay	silt	sand	sand_silt	den_all	ba_all	den_pine	ba_pine	den_oth1	ba_oth1
C1_53	2.602	45.273	52.125	97.398	90	6.219	90	6.219	0	0
C1_54	3.525	48.1732	48.3018	96.475	400	14.884	30	4.172	370	10.712
C1_57	2.602	45.273	52.125	97.398	190	5.392	190	5.392	0	0
C1_58	2.94	35.0711	61.9889	97.06	200	11.531	185	11.486	15	0.045
C1_59	2.74667	51.92	45.3333	97.2533	330	2.549	330	2.549	0	0
C1_60	2.39	39.9392	57.6708	97.61	206.66	13.217	193.33	13.106	13.33	0.111
C2_53	2.51222	42.11	55.3778	97.4878	550	21.358	540	21.235	10	0.123
C2_54	3.525	48.1732	48.3018	96.475	160	12.922	130	12.548	30	0.374
C2_56	2.602	45.273	52.125	97.398	480	15.953	480	15.953	0	0
C2_57	2.602	45.273	52.125	97.398	380	10.258	380	10.258	0	0
C2_58	3.525	48.1732	48.3018	96.475	360	15.312	210	15.189	150	0.123
C2_59	3.525	48.1732	48.3018	96.475	960	18.675	150	18.395	810	0.28
C2_62	2.39	39.9392	57.6708	97.61	520	5.257	220	4.26	300	0.997
C2_63	2.39	39.9392	57.6708	97.61	506.67	18.601	313.33	14.212	193.34	4.389
C2_64	2.39	39.9392	57.6708	97.61	340	14.774	153.33	11.847	186.67	2.927
C3_51	2.602	45.273	52.125	97.398	790	23.493	790	23.493	0	0
C3_52	3.525	48.1732	48.3018	96.475	510	13.589	80	5.537	430	8.052
C3_54	2.602	45.273	52.125	97.398	460	17.571	290	15.642	170	1.929
C3_55	3.525	48.1732	48.3018	96.475	245	10.313	180	10.236	65	0.077
C4_53	2.51222	42.11	55.3778	97.4878	300	8.507	280	8.366	20	0.141
C4_54	2.63	19.17	78.2	97.37	486.67	11.763	93.33	7.459	393.34	4.304
C4_56	3.525	48.1732	48.3018	96.475	626.67	6.551	613.34	6.548	13.33	0.003
C4_57	2.602	45.273	52.125	97.398	1230	8.959	800	8.03	430	0.929
C4_58	2.94	35.0711	61.9889	97.06	245	11.233	245	11.233	0	0
C4_59	3.525	48.1732	48.3018	96.475	453.34	9.849	113.33	6.842	340	3.007
C4_62	2.63	59.82	37.55	97.37	725	17.054	700	16.747	25	0.307
C5_54	2.51222	42.11	55.3778	97.4878	289.74	9.385	289.74	9.385	0	0

Appendix PL1 (continued)

E.

plot	clay	silt	sand	sand_silt	den_all	ba_all	den_pine	ba_pine	den_oth1	ba_oth1
C5_55	3.525	48.1732	48.3018	96.475	258.47	7.097	54.94	4.472	203.52	2.625
C5_57	3.525	48.1732	48.3018	96.475	570	7.659	310	7.647	260	0.012
C5_58	2.39	39.9392	57.6708	97.61	1810	7.195	160	2.829	1650	4.366
C5_59	3.525	48.1732	48.3018	96.475	198.61	10.535	148.61	10.534	50	0.001
C5_60	3.525	48.1732	48.3018	96.475	121.14	7.75	121.14	7.75	0	0
C5_62	2.602	45.273	52.125	97.398	940	7.793	940	7.793	0	0
C5_63	3.525	48.1732	48.3018	96.475	520	16.177	520	16.177	0	0
C6_51	3.525	48.1732	48.3018	96.475	1150	5.886	100	2.326	1050	3.56
C6_52	2.94	35.0711	61.9889	97.06	210	11.173	200	11.173	10	0
C6_54	2.602	45.273	52.125	97.398	6630	14.522	780	14.408	5850	0.114
C6_55	2.94	35.0711	61.9889	97.06	920	16.752	700	13.215	220	3.537
C7_52	2.602	45.273	52.125	97.398	330	6.848	190	6.845	140	0.003
C7_53	2.39	39.9392	57.6708	97.61	360	11.547	140	11.341	220	0.206
P1	2.63	59.82	37.55	97.37	1250	26.354	625	25.93	625	0.424
P10	2.51222	42.11	55.3778	97.4878	8750	129.443	5300	119.45	3450	9.993
P11	2.51222	42.11	55.3778	97.4878	910	34.762	790	33.925	120	0.837
P2	2.63	59.82	37.55	97.37	600	19.465	416.67	19.447	183.33	0.018
P3	3.525	48.1732	48.3018	96.475	1830	30.064	1550	28.539	280	1.525
P31	2.51222	42.11	55.3778	97.4878	860	28.854	590	23.105	270	5.749
P33	2.51222	42.11	55.3778	97.4878	820	32.861	600	30.181	220	2.68
P4	2.602	45.273	52.125	97.398	720	21.801	720	21.801	0	0
P42	3.525	48.1732	48.3018	96.475	1600	35.008	1170	30.706	430	4.302
P43	3.525	48.1732	48.3018	96.475	1550	19.248	1150	15.094	400	4.154
P46	3.525	48.1732	48.3018	96.475	1120	24.395	750	23.537	370	0.858
P5	2.63	59.82	37.55	97.37	140	5.917	140	5.917	0	0
P53	2.602	45.273	52.125	97.398	850	14.698	270	13.956	580	0.742
P55	2.602	45.273	52.125	97.398	780	21.658	570	21.643	210	0.015

Appendix PL1 (continued)

F.

plot	clay	silt	sand	sand_silt	den_all	ba_all	den_pine	ba_pine	den_oth1	ba_oth1
P6	2.602	45.273	52.125	97.398	560	16.572	520	16.395	40	0.177
P61	3.525	48.1732	48.3018	96.475	710	23.614	360	22.977	350	0.637
P66	3.525	48.1732	48.3018	96.475	1040	22.84	770	20.641	270	2.199
P67	3.525	48.1732	48.3018	96.475	140	16.05	130	15.652	10	0.398
P7	3.525	48.1732	48.3018	96.475	1437.5	14.231	1225	14.116	212.5	0.115
P72	2.602	45.273	52.125	97.398	870	6.415	410	6.367	460	0.048
P74	2.39	39.9392	57.6708	97.61	483.33	5.152	200	3.481	283.33	1.671
P77	2.602	45.273	52.125	97.398	530	8.757	510	8.735	20	0.022
P78	2.602	45.273	52.125	97.398	1820	1.881	1280	1.817	540	0.064
P79	2.602	45.273	52.125	97.398	850	10.592	780	10.588	70	0.004
P8	2.39	39.9392	57.6708	97.61	5860	8.429	5020	8.181	840	0.248
P81	2.39	39.9392	57.6708	97.61	780	22.959	460	12.125	320	10.834
P82	2.39	39.9392	57.6708	97.61	620	17.272	560	16.104	60	1.168
P83	2.39	39.9392	57.6708	97.61	930	29.961	850	27.33	80	2.631
P9	2.63	59.82	37.55	97.37	.	.	.	.	.	.

Variables defined:

stand type 1=reference, 2=plantation
CEC=cation exchange capacity
Ksat= K base saturation
Mgsat=Mg base saturation
Casat=Ca base saturation
pH
OM=Organic matter (%)
K=ppm K
Mg=ppm Mg
Ca=ppm Ca
series = soil series

den_all = density of all trees and saplings in a plot
ba_all = basal area of all trees and saplings in a plot
den_pine = density of all pines, trees and saplings
ba_pine = basal area of all pines, trees and saplings
den_oth1 = density of all non-pine trees and saplings
ba_oth1 = density of all non-pine trees and saplings
den_oak = density of all oak trees and saplings
ba_oak = basal area of all oak trees and saplings
den_oth2 = density of all trees and saplings that are neither pines or oaks
ba_oth2 = basal area of all trees and saplings that are neither pines or oaks

Appendix 1.

Technical Publications and Presentations

Publications

Cohen, S. and J. Walker. 2005. Early longleaf pine seedling survivorship on hydric soils. Proc. 13th Biennial Southern Silvicultural Research Conference. February 28 – March 4. Memphis, TN.

Knapp, B.O. and J.L. Walker. 2009. Using existing growth models to predict RCW habitat development following site preparation: pitfalls of the process and potential growth response. Proceedings of the 15th Biennial Southern Silvicultural Research Conference. November 17-20, 2008. Hot Springs, AR [*submitted*].

Knapp, B.O., G.G. Wang, and J.L. Walker. 2008. Relating the survival and growth of planted longleaf pine seedlings to microsite conditions altered by site preparation treatments. Forest Ecology and Management 225(11): 3768-3777.

Knapp, B.O., G.G. Wang, and J.L. Walker. Artificially regenerating longleaf pine on wet sites: preliminary analysis of effects of site preparation treatments on early survival and growth. Proceedings of the 14th Biennial Southern Silvicultural Research Conference. February 26-March 1, 2007. Athens, GA. [*In press*].

Knapp, B.O., G.G. Wang, J.L. Walker, and S. Cohen. 2006. Effects of site preparation treatments on early growth and survival of planted longleaf pine *(Pinus palustris* Mill.) seedlings in North Carolina. Forest Ecology and Management 223(1-3): 122-128.

Knapp, B.O., G.G. Wang, and J.L. Walker. 2004. Effects of site preparation on the first year growth of planted longleaf pine seedlings. Proceedings of Society of American Foresters and Canadian Institute of Forestry 2004 Joint Annual General Meeting and Convention. October 2-4. Edmonton, Alberta, Canada.

Walker, J.L., Silletti, A.M., Cohen, S., 2007. Composition and structure of managed pine stands compared to reference longleaf pine sites on Camp Lejeune, NC. Proc. 14th Biennial Southern Silvicultural Research Conference. Athens, GA.

Manuscripts in preparation for publication

Cohen, S., S. Zarnoch, and J. Walker. Initial effects of longleaf pine flatwoods management on soil nutrients. Being revised according to reviewers' comments for Forest Ecology and Management.

Walker, J.L., B.O. Knapp, A.S. Silletti, S. Cohen. Ground layer vegetation responses to moderate site preparation methods on North Carolina flatwoods sites. In preparation for Forest Ecology and Management.

Walker, J.L. Site preparation treatments in wet flatwoods sites affect prescribed fire behavior in young plantations. In preparation for Southern Journal of Applied Forestry.

Presentations

Oral

Walker, J.L., Silletti, A.M., Cohen, S., 2007. Composition and structure of managed pine stands compared to reference longleaf pine sites on Camp Lejeune, NC. Proc. 14th Biennial Southern Silvicultural Research Conference. Athens, GA.

Knapp, B.O., J.L. Walker, S. Cohen, and A.M. Silletti. 2007. Early effects of site preparation on the native ground layer vegetation of a hydric soil in North Carolina, USA. 2007 Ecological Society of America/Society for Ecological Restoration Joint Meeting. August 4-11, 2007. San Jose, CA.

Knapp, B.O., G.G. Wang, and J.L. Walker. 2007. Artificially regenerating longleaf pine on wet sites: preliminary analysis of effects of site preparation treatments on early survival and growth. 14th Biennial Southern Silvicultural Research Conference. February 26-March 1. Athens, GA.

Knapp, B.O., G.G. Wang, and J.L. Walker. 2006. Effects of site preparation treatments on microsite conditions in relation to growth and survival of planted longleaf pine seedlings in North Carolina. ESA 91st Annual Meeting. August 6-11. Memphis, TN.

Posters

2008. The Partners in Environmental Technology Technical Symposium and Workshop. December 4-6, 2007. Washington, DC.

Knapp, B.O. and J.L. Walker. 2008. Using existing growth models to predict RCW habitat development following site preparation: pitfalls of the process and potential growth response. 15th Biennial Southern Silvicultural Research Conference. November 17-20, 2008. Hot Springs, AR.

Walker, J.L., et al. 2007. IUFRO workshop. Seoul, Korea

Knapp, B.O., J.L. Walker, S. Cohen, and A.M. Silletti. 2007. Plantation management effects on ground layer vegetation: short-term effects diminish but long-term differences are evident. The Partners in Environmental Technology Technical Symposium and Workshop. December 4-6, 2007. Washington, DC.

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